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BULLETIN OF MARINE SCIENCE
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VOLUME 9 1959 NUMBER 1

WATER MASS PROPERTIES OF THE STRAITS OF FLORIDA AND RELATED WATERS[1]

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ABSTRACT

The hydrography of the Straits of Florida is greatly influenced by a flow of water originating in the Caribbean-Gulf of Mexico region and to a lesser extent by waters of the Western Atlantic. The Caribbean or Yucatan Water, identified by its well-defined salinity maximum, is found along the entire insular margin of the Florida Current. Evaporation and seasonal cooling modify the upper 300 m of the original Yucatan Water, creating new water masses in the northern and western Gulf of Mexico. The Continental Edge Water, a water mass somewhat intermediate between Yucatan and Western Gulf Waters, becomes well-differentiated in the eastern Gulf, being easily identified by temperature-salinity and oxygen-density relationships. The Continental Edge Water is found along the continental margin of the Florida Current throughout the length of the Straits. The influx of Western Atlantic Water is frequently observed in the northern Straits of Florida off Bimini, being detected by its higher oxygen content; it is restricted to a narrow band along the Bahama Banks. The study of oxygen distribution shows that Western Atlantic Water intermixes with the waters flowing out of the Straits of Florida. Present information on dissolved inorganic phosphate is too unreliable to permit a critical study of its distribution. The Straits of Florida are part of an extensive sill preventing interchange of waters from depths greater than about 800 m between the Gulf of Mexico and the Atlantic Ocean. The sill depth of the Straits of Florida and portions of the Blake Plateau is slightly below the average depth of the oxygen minimum and is exactly within the average depth of the dissolved inorganic phosphate maximum.

INTRODUCTION

Oceanographically, the Straits of Florida are unique: a major ocean current is restricted within the narrow confines of a somewhat shallow channel bounded on the west by the continental United States and on the east by the Bahamian-Caribbean archipelago. Its hydrography is dominated by the fast flowing Florida Current, one of the major sub-

[1]Contribution No. 200 from The Marine Laboratory, University of Miami. This constitutes a final report to the National Science Foundation (Grant #G2579) and a Technical report to the Office of Naval Research (Grant #Nonr-840(01)).

divisions of the Gulf Stream system. The waters of the Straits of Florida are part of a transient system and the properties of the waters are acquired outside the Straits. For these reasons, the relationships between the waters of the Florida Current and those of the surrounding area must be examined.

In recent years, more and more emphasis has been placed upon the Gulf Stream as a major factor influencing the meteorology of the Atlantic regions of the northern hemisphere. Studies of its mass transport were pushed in order to speculate on and attempt to predict fluctuations in its heat transport to higher latitudes. These investigations focused the attention of researchers on the intricacies of the current system rather than on the properties of the water, investigators being concerned mainly with a search for the prime moving force of the Gulf Stream. An excellent summary of the theories and ideas dealing with such a search has been written by Stommel (1950) and a new approach to the problem was outlined by Charney (1955).

The waters of the Florida Current are important not only to meteorologists but also to biologists. They have a great influence upon the ecology and biology of the waters of the southeastern United States. A better understanding of the magnitude and distribution of elements influencing the basic biological production of these waters necessitates a reappraisal of our hydrographic knowledge of the region.

Remoteness of the area from major oceanographic institutions on the North American continent was, until recent years, a major obstacle to more intensive studies of the hydrography of the Gulf of Mexico and Straits of Florida. Before World War II, Woods Hole Oceanographic Institution was the principal agency operating in the region. Since that time, the establishment of The Marine Laboratory, University of Miami and the Department of Oceanography, Agricultural and Mechanical College of Texas, has contributed to the intensification of oceanographic research.

This report is a result of investigations conducted at The Marine Laboratory, University of Miami, between September 1956 and September 1957 under the joint sponsorship of the National Science Foundation and the Office of Naval Research. Sincere appreciation is extended to Lansing P. Wagner and Robert C. Work whose perseverance permitted the gathering of much-needed data, to Dr. F. F. Koczy who stimulated new ideas, to Mr. Frank Chew and Miss Anita Feinstein for their helpful suggestions, and to Mrs. Ellen Roseman

and Mr. John H. G. Stimson who performed the necessary laboratory analyses.

Objectives of the Research. This report is an attempt to synthesize old and new studies of the relationships between salinity, temperature, dissolved oxygen, and inorganic phosphate in the Straits of Florida and related waters.

The specific objectives of the research are: 1) to define the water masses of the Straits of Florida and to investigate their relationships to the waters of the surrounding areas; 2) to investigate the relationship between temperature, salinity, and density distribution and corresponding oxygen and phosphate values and the possibilities of using the latter as tracers of water masses in the Straits; and 3) to investigate the mechanisms which influence and control the distribution of oxygen and phosphate in the Straits.

Description of the Area. In order to undertake a comprehensive analysis of water mass properties within a rather limited amount of time, the study was restricted to the waters of the Yucatan Channel, the eastern Gulf of Mexico, the Straits of Florida, portions of the Bahama channels directly connected with the Straits of Florida, and the northern approaches to the Straits to the latitude of Jacksonville.

A very good summary of the general climatology and meteorology of the region can be found in the U.S.C. & G.S. Coast Pilot, Gulf of Mexico (1949). On the average, the pressure pattern underlying the general circulation of air tends to follow the sweep of the western extension of the Bermuda high pressure cell during spring and summer months. In the late summer there is a northward shift of the general circulation, the region coming under the more direct influence of the equatorial low pressure belt (doldrums). By fall, the building of higher pressures over the North American continent modifies the pattern and during the winter, the general circulation is greatly influenced by a succession of highs and lows sweeping from west to east across the continent.

The influence of the climatology upon the hydrography of the northeastern Gulf of Mexico will be discussed in Section III.

Previous Investigations. The first comprehensive analysis of the hydrography of the Straits of Florida and adjacent Atlantic waters was made by Wüst (1924). He commented on the possible influence of the bottom topography on the circulation of the deep water in the Straits of Florida, and in fact was the only investigator to do so.

It was not until 1931 that an extensive analysis of the hydrography of the Gulf of Mexico and Straits of Florida was undertaken by Parr. The findings of Parr (1935a; 1937a,b; 1938) included all of the previous works and to date are the only available studies describing the distribution of temperature and salinity in the area in detail.

Dietrich (1939) broadened the scope of Parr's studies by including the distribution of oxygen with temperature and salinity for the entire Caribbean, Gulf of Mexico, Straits of Florida and adjacent Atlantic waters.

The above investigations form the fundamental framework of our present knowledge of the hydrographic conditions in the area under study.

The General Circulation. The general pattern of circulation indicates that a line drawn between the Mississippi delta and the southwestern tip of Cuba forms the boundary between currents having different directions. East of the line the current generally flows to the east and south; west of it, the current flows north and west.

It must be remembered that these observations pertain to surface currents only. Nothing is known at present of the general circulation of waters deeper than about 400 fathoms in this area.

The work of Pillsbury (1890) is still the basis of our knowledge of the magnitude of the current velocities. Pillsbury results, based upon direct measurements, show that for every section investigated, i.e., the Yucatan Channel, the western approaches to the Straits of Florida, the southern Straits of Florida and the northern Straits of Florida, the highest velocities are usually found to the left of the axis of direction of transport.

A very important feature of the Florida Current must be taken into account in the interpretation of hydrographic data collected in the Straits of Florida and elsewhere along the Gulf Stream: the current meanders. In recent years, much attention has been focused on the extent and variability of the meanders of the stream (Fuglister, 1951; Worthington, 1954; Von Arx, *et al.*, 1954). All of these investigations deal with the Gulf Stream near Cape Hatteras and beyond. Recent studies conducted in the Straits of Florida (Hela, Chew, and Wagner, 1955; Hela, Wagner, and Chew, 1955; Chew and Wagner, 1956, 1957) indicate that meanders are common occurrences. The origin and behavior of these meanders, which are best identified along the left hand margin of the stream, are still speculative. Meanders can be

triggered by complex hydrodynamic processes, but the possibilities that they are initiated by bathymetric features must be considered seriously (Haurwitz and Panofsky, 1950; Stockmann, 1952).

The importance of the bathymetry as a direct influence upon the behavior of the stream in the Straits of Florida has been completely overlooked in the past. The fact that the axis of the Florida Current flows over a portion of the Florida Keys Bank, an area of varied relief, suggests that changes could occur in the internal structure of the stream. The possible influence of the bathymetry upon the distribution of water mass properties will be discussed in Section I.

Section I. Bathymetry

A. General Bathymetry

The region can be subdivided into several well-defined bathymetric provinces (see Fig. 1):

1. *The Yucatan Sill.* The Yucatan sill separates the Caribbean Sea from the Gulf of Mexico. The sill depth appears to be about 1,150 fathoms (2,100 m) at its deepest point.

2. *The Gulf of Mexico.* The Gulf of Mexico Basin is a relatively simple depression lacking the bottom irregularities that characterize the Caribbean region.

In the eastern Gulf of Mexico, several bathymetric features have important bearings upon the general hydrography of the area. The northern portion of Campeche Bank blocks direct access of deep water from the western Gulf to the western approaches of the Straits of Florida. The 100 fathom line along Campeche Bank reaches latitude 24°N, corresponding to about two-thirds of the distance between the Florida Keys and Cuba, while the 1,000 fathom line extends to the latitudes of the Florida Keys. The water depths over the bank proper are for the most part less than 40 fathoms.

An extensive shallow shelf is present off the west coast of Florida. The shelf area shallower than 100 fathoms is slightly over 4,300 square nautical miles, with most of the depths less than 40 fathoms. The shelf narrows between Cape San Blas and the Mississippi delta.

3. *The Blake-Bahamian Platform.* The Blake-Bahamian Platform refers to the extensive submarine plateau bordering the southeastern coast of the continental United States.

The Blake-Bahamian Platform includes the bathymetric features of: 1) the Blake Plateau, between Cape Hatteras and the Bahama Islands; 2) the Straits of Florida; and 3) the Bahamian Platform. The Blake

FIGURE 1. General Bathymetry, eastern Gulf of Mexico, Straits of Florida, Bahamas.

Plateau is about 150 miles wide with water depths averaging between 300 and 500 fathoms. From the latitude of Jacksonville southward, the eastern margin of the plateau is well defined by the 800 to 1,000 fathom contours. The Bahamian Platform, between the latitude of southern Florida and the island of Cuba, is an area of rugged submarine relief. The eastern border of the platform is highly dissected and is indented by deep basins with depths in excess of 700 fathoms. These basins are surrounded by the extensive Bahama Banks which usually shoal to about one or two fathoms. For a comprehensive description of the Bahamian Platform, one should refer to the excellent work of Newell (1951, 1955).

The Bahamian Platform is transected by two major channels with northwest-southeast axes which afford easterly openings between the Straits of Florida and the western Atlantic. The Old Bahama Channel, between the southern Bahama Bank and Cuba, is fairly narrow, i.e., about 15 miles wide, and is about 100 miles long. Water depths are between 250 and 300 fathoms. Northwest Providence Channel, between the Little and Great Bahama Banks, connects the Northern Straits of Florida with the Tongue of the Ocean and the western Atlantic. The greatest portion of the channel has depths in excess of 500 fathoms, shoaling to about 370 fathoms at its deepest connection with the Straits.

B. The Straits of Florida.

The general shape of the Straits of Florida is that of an inverted "L." The Straits form a continuous channel, except in the southern portion where Cay Sal Bank, a large shoal about 60 miles long and 40 miles wide, subdivides the channel into: a) Santaren Channel between Cay Sal and the Great Bahama Bank and b) Nicholas Channel, between Cay Sal Bank and Cuba. These two channels merge forming the western approaches to the Old Bahama Channel.

The Straits of Florida can be subdivided into several well defined bathymetric provinces (Fig. 2):

1. *Northern Straits*. The Northern Straits, extending from the latitude of Jupiter Inlet, Florida, to Cay Sal Bank, can be considered as a logical extension of the Blake-Bahamian Platform. The main axis of the channel is well defined by the 400 fathom contour, with maximum depths averaging about 450 fathoms.

The shallowest portion of the Straits of Florida is found between the northern portion of the Little Bahama Bank and Fort Pierce Inlet,

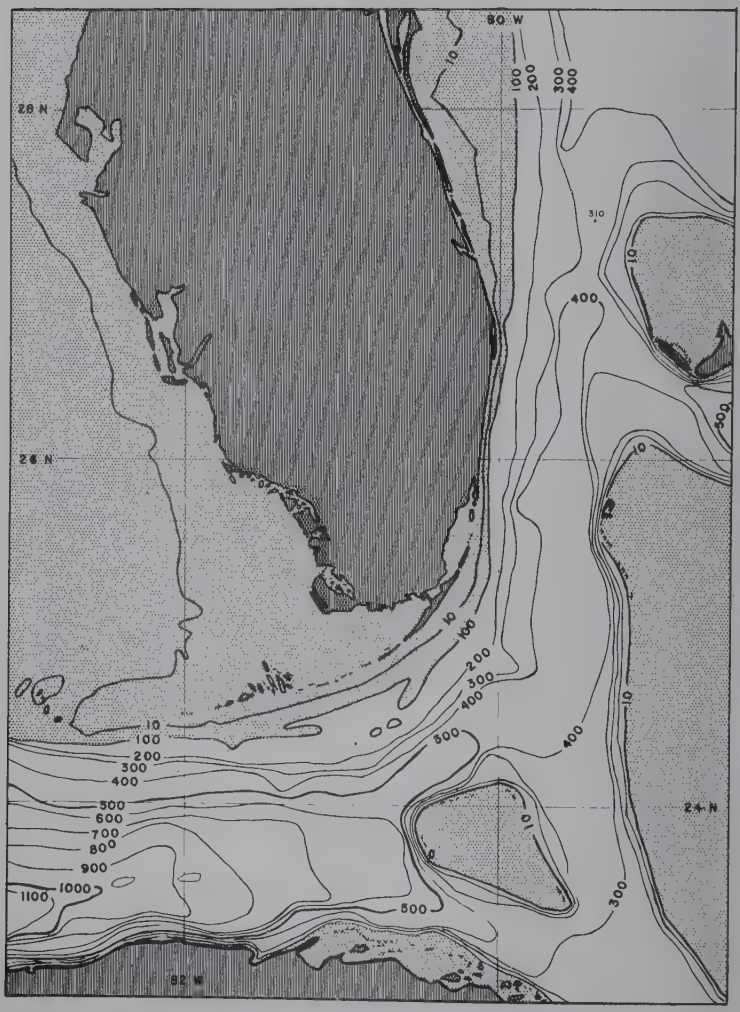

FIGURE 2. Straits of Florida, general bathymetry.

Florida (U.S.C. & G.S. chart #1112). The sill depth is about 310 fathoms.

The bottom topography of the eastern portion of the channel apparently is simple: steep slopes are found along the Bahama Banks. The western portion of the channel has a pronounced shelf with varied bathymetric features. The margin of the shelf is approximately delineated by the 200 fathom contour.

2. *The Cay Sal Region.* The section of the Straits of Florida between Cay Sal Bank and the Florida Keys has a very important bathymetric feature, the Florida Keys Bank. The bank is a submarine plaform located on the eastern side of the Florida Keys. The edge of the platform can be defined by the 200 to 250 fathom contour.

The platform reaches its greatest width between Cay Sal and the Keys, extending nearly one-half the distance between the two. The platform is well defined from the Marquesas Keys to Fowey Rocks, Miami. The submarine relief of the Florida Keys Bank appears to be varied.

3. *The Southern Straits.* The Southern Straits can be defined as the portion of the Straits of Florida which extends from the Marquesas Keys to the western abutment of Cay Sal Bank.

The bathymetry of the Southern Straits can be considered as an extension of the general bathymetry of the Gulf of Mexico. Depths are in excess of 500 fathoms, the axis of the trough rising from about 1,100 fathoms off the Dry Tortugas to about 500 fathoms at the western edge of Cay Sal Bank. The channel slopes along the island of Cuba are extremely sharp.

Section II. Sources and Processing of Data

An attempt was made to gather all the hydrographic data pertaining to the region under investigation; a relatively large amount is available, mostly in tabulated form. The data were then scrutinized to select those which would give simultaneous correlation among the various water mass properties, i.e., temperature, salinity, oxygen, and inorganic phosphate.

While many salinity and temperature data are readily available, simultaneous temperature, salinity, and oxygen data are relatively scarce and phosphate data are few and often of questionable validity. The data in Table 1 were selected as representative for the purposes of this study.

TABLE 1
SOURCES OF DATA

Stations	*Date*		*T.S.O_2.PO_4.*
I. *Yucatan Channel.*			
ATLANTIS station 1606	May	1933	T.S.O_2.PO_4.
ATLANTIS stations 2333-2337	February	1935	T.S.O_2.
Texas A. & M. stations 1-1A-13 to 18	April	1951	T.S.
Texas A. & M. stations 4-2A-14 to 18	January	1952	T.S.PO_4.
CARYN cruise 96	May	1956	T.S.O_2.
II. *Gulf of Mexico.*			
ATLANTIS stations 2338-2382	March	1935	T.S.O_2.
ATLANTIS stations 2421-2433	April	1935	T.S.O_2.
Texas A. & M. cruise 1-1A	May	1951	T.S.
Texas A. & M. cruise 3-1C	August	1951	T.S.
Texas A. & M. cruise 4-2A	January	1952	T.S.PO_4.
Texas A. & M. stations 54-10-12 to 16	August	1954	T.S.O_2.
U of M. cruise P 420, stations 20-29	April	1954	T.S.
U of M. Red Tide studies	1954 -	1956	T.S.
III. *Straits of Florida.*			
a. Key West - Havana.			
ATLANTIS stations 2343-2347	February	1935	T.S.O_2.
ATLANTIS stations 2434-2438	April	1935	T.S.O_2.
Texas A. & M. stations 1-1A-23 to 27	May	1951	T.S.
Texas A. & M. stations 4-2A-27 to 30	January	1952	T.S.PO_4.
U of M. cruise P 420, stations 5-16	April	1954	T.S.
U of M. cruise G 5705, stations 1-7	April	1957	T.S.O_2.PO_4.
b. Miami - Bimini.			
U of M. cruise P 513	April	1955	T.S.O_2.
U of M. cruise P 514	April	1955	T.S.O_2.
U of M. cruise P 515	April	1955	T.S.O_2.
U of M. cruise G 5506	August	1955	T.S.O_2.
U of M. cruise G 5520	November	1955	T.S.O_2.PO_4.
U of M. cruise G 5524	December	1955	T.S.O_2.
U of M. cruise G 5601	January	1956	T.S.O_2.
U of M. cruise G 5609	March	1956	T.S.O_2.
U of M. cruise G 5611	May	1956	T.S.O_2.
U of M. cruise G 5623	November	1956	T.S.O_2.PO_4.
ATLANTIS stations 5155-5162	February	1954	T.S.O_2.
IV. *Northern Approaches to the Straits of Florida.*			
ATLANTIS stations 1611-1626	May	1933	T.S.O_2.PO_4.
ATLANTIS stations 1633-1642	May	1933	T.S.O_2.PO_4.
T. N. GILL cruise 1.	February	1953	T.S.O_2.PO_4.
T. N. GILL cruise 2.	April	1953	T.S.O_2.PO_4.
V. *Bahamas and Western Sargasso Sea.*			
ATLANTIS stations 1475-1478	February	1933	T.S.O_2.PO_4.
T. N. GILL cruise 1.	February	1953	T.S.O_2.PO_4.
T. N. GILL cruise 2.	April	1953	T.S.O_2.PO_4.
H. O. SAN PABLO cruise 72. sta. 24-27	April	1953	T.S.O_2.
H. O. REHOBOTH cruise 73. sta. 28-31	April	1953	T.S.O_2.
H. O. cruise 448	October	1953	T.S.O_2.
H. O. cruise 477	November	1954	T.S.O_2.
H. O. cruise 494	June	1954	T.S.O_2.

The greatest handicap to a comprehensive study of the distribution of water mass properties must be noted here: except for those collected on the Miami-Bimini transect, where a complete seasonal sampling is available, the data lack continuity. In the other areas, often as many as 20 years have elapsed between hydrographic samplings. Most of the data from Yucatan Channel and Gulf of Mexico were collected in the winter and spring, leaving large gaps in the annual picture for these areas.

On the basis of a critical review of previous work, the data were processed as follows:

1. *Temperature and salinity.* The temperature and salinity data for every station were plotted to show Temperature-Salinity (T-S) relationships which then were sorted into groups having common characteristics. A spatial distribution of T-S curves with similar characteristics was obtained.

2. *Dissolved oxygen.* The oxygen data were plotted as oxygen-density (O_2-σ_t) relationships for each station having corresponding temperatures and salinities. The O_2-σ_t curves then were sorted to correspond with the groups of T-S diagrams.

3. *Dissolved inorganic phosphate.* The phosphate data were plotted as phosphate-density (PO_4-σ_t) relationships and then sorted as above.

Although this method of processing the data is perhaps crude and subject to some bias, for the present it should be considered as a first approach to the study of the distribution of water mass properties. The validity and limitations of the method will be discussed later.

Section III. Identification of Water Masses

It was necessary to establish the identities of the water masses of the area under study before any studies of the distribution of dissolved oxygen and inorganic phosphate could be undertaken. Examination of available hydrographic data and analysis of the findings of Parr (1937a) and Dietrich (1939) had indicated the possible presence of more than one water mass in the Straits of Florida.

The Temperature-Salinity (T-S) relationships were used first to identify and investigate the relationships among waters of various origins.

A. Yucatan Channel

The waters flowing through the Straits of Florida come from the Gulf of Mexico. However, this primary source of water for the entire

system depends upon the influx of Caribbean water flowing through Yucatan Strait.

The T-S curves plotted in Figure 3A define what will be referred to as Yucatan Water. The curves plotted in a single T-S diagram represent all of the temperature and salinity data available for the Yucatan Strait, regardless of the cross-channel distribution of the sampling stations. No significant differences were observed between T-S characteristics, except at stations on the western side of the strait where, at times, a decrease in the magnitude of the salinity maximum was observed. It should be noted that while there is a spread between extremes of T-S characteristics, the majority of the curves are in a very narrow range, especially below 200 m.

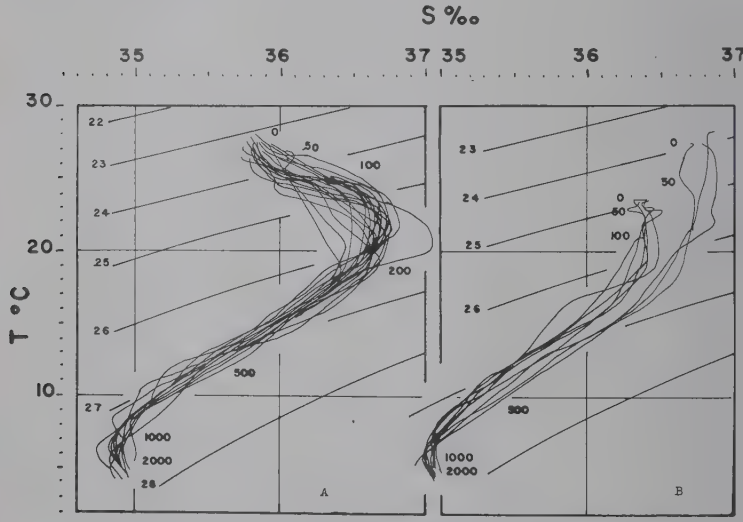

FIGURE 3. Temperature-Salinity relationships: A—Yucatan Strait. B—Western Gulf of Mexico.

The upper portion of the Yucatan Water T-S curve suggests waters mainly of North Atlantic origin with a considerable admixture of South Atlantic water. A considerable amount of Antarctic Intermediate water is suggested by the T-S curve between 200 and 1,000 m, the salinity minimum being attributed to waters of mainly South Atlantic origin (Sverdrup, *et al.*, 1946). The origin of the water below about

1,500 m is still a matter for speculation. Worthington (1955) indicated that such water might come from the North Atlantic.

B. Eastern Gulf of Mexico

The eastern Gulf of Mexico is an area of oceanographic transition, fed by the waters of the Caribbean. Part of this water flows east through the Straits of Florida; the rest flows north to intermix with the waters of the western Gulf and coastal regions of the southern United States.

Analysis of the T-S relationships for the eastern Gulf of Mexico indicate that three water masses can be identified:

1. *Yucatan Water.* The Yucatan Water is readily identified by its T-S characteristics, as defined above. The spatial distributions of the T-S curves afford an easy means of determining the extent of its boundaries as it penetrates the waters of the eastern Gulf.

The average position of the northern limit of the Yucatan Water appears to correspond to a latitude slightly south of Tampa. The western boundary roughly follows a line drawn along the 100 fathom contour along the eastern portion of Campeche Bank to the Mississippi delta. While few investigations of the water mass characteristics of the western edge of the Yucatan Water have been made, a preliminary examination of the T-S characteristics of the region shows that, at times, marked changes can be observed in the shape of the T-S curve, suggesting a region of intermixing between the waters of the western Gulf and the Yucatan Water.

The eastern edge of the Yucatan Water appears to be roughly slightly to the east of the 1,000 fathom contour, off the Florida Shelf.

Seasonal variations can be observed in the upper 150 m of the Yucatan Water (Fig. 4B,D), temperatures fluctuating between about 27°C in the late winter and about 29.5°C to 30°C in the summer. The waters below 150 m do not exhibit seasonal fluctuations.

2. *Western Gulf Water.* Western Gulf Water is defined to mean a water mass found west of a line drawn between the Yucatan Peninsula and the Mississippi delta. The water mass has the following T-S characteristics (Fig. 3B):

These T-S relationships are based on data collected by Texas A. & M., Department of Oceanography, between latitudes 22°N and 26°N and longitudes 90°W and 96°W.

Examination of the T-S curve shows that the upper 100 m exhibit seasonal temperature variations ranging between 22°C and 29°C, although salinities are unchanged.

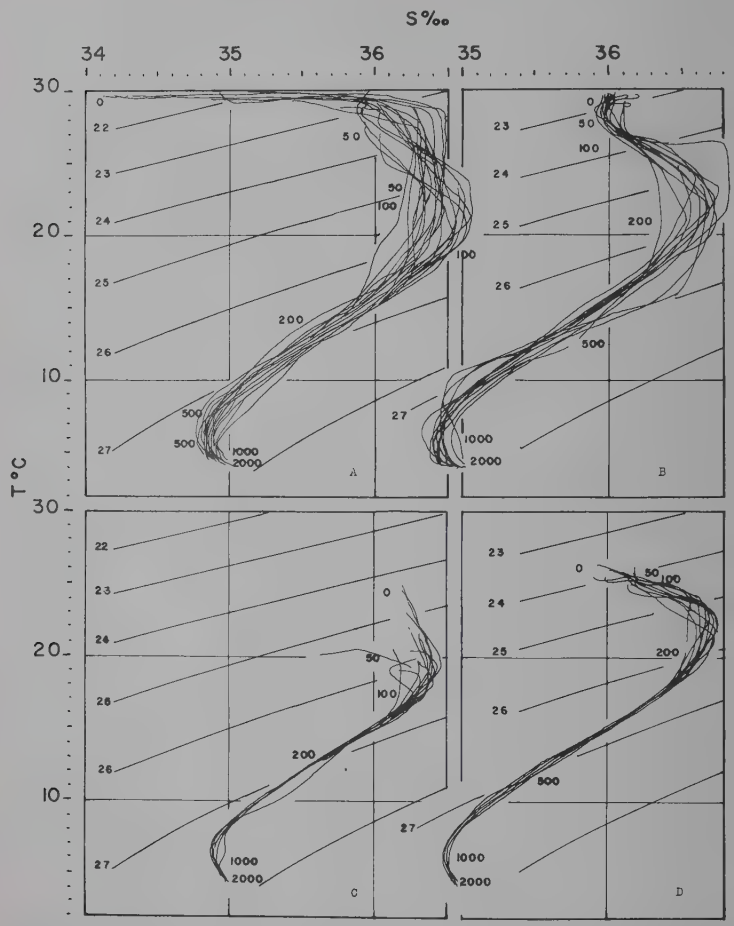

FIGURE 4. Temperature-Salinity relationships, Eastern Gulf of Mexico. Continental Edge Water: A, Summer. C, Winter. Yucatan Water: B, Summer. D, Winter.

The waters of the western Gulf of Mexico cannot be discussed fully in this study. However, since some of that water penetrates the eastern Gulf, identification of the water masses was necessary.

3. *Continental Edge Water.* Continental Edge Water or Edge Water is defined to mean the waters of the eastern Gulf of Mexico located between the northern and eastern edge of the Yucatan Water and the coastal regions of the southern United States, between the Mississippi delta and the western tip of Florida.

To define the water mass characteristics of the Edge Water on the basis of T-S relationships presents a rather complex problem. The T-S curves do not form an homogeneous pattern as do the Yucatan and Western Gulf Waters, although some of the T-S characteristics appear to form an intermediate group. Data collected in 1935 by the ATLANTIS and on Texas A. & M. cruise 54-10 (1954) illustrate the T-S relationships of the Edge Water. The ATLANTIS data represent late winter, those from Texas A. & M. late summer (Fig. 4A,C).

The most conspicuous feature of the Edge Water is the great reduction of the intensity of the salinity maximum. The upper portion of the curve, between the surface and about 200 meters, has salinities ranging between 36.1 ‰ and 36.6 ‰. Land drainage discharge is reflected in lower salinities down to about 40 m at certain stations. Marked seasonal temperature variations can be observed; winter temperatures range from as high as 26°C at the surface to about 19°C at 100 m, while summer temperatures range between 30°C and 20°C for the same depths. In both seasons the T-S curve crosses the isopycnal at nearly a right angle, from the surface to about 150 m.

A significant feature of the Edge Water is the great similarity between its T-S curves and those of the Western Gulf, below 200 m. The T-S curves of both water masses show identical variations in the depth at which a given σ_t is observed as compared to the depth of similar σ_t values in the Yucatan Water.

The differentiation between the Edge Water and Yucatan Water is found mainly in the upper 300 m. Below about 300 m, both T-S characteristics merge within a single narrow envelope.

Two main processes which appear to be involved in the formation of new water masses in the Gulf of Mexico can be postulated: 1) evaporation and 2) cooling. An examination of the available data indicates that the salinities of the surface water in the Gulf of Mexico are generally higher than in the Yucatan Water, except in areas immediately adjacent to major land drainage outlets. Since the influence of land drainage is usually confined to the upper 30-40 m, the salinity increase can only be attributed to evaporation occurring over most of the Gulf, probably during fall and winter months (Jacobs, 1951).

There are marked seasonal temperature fluctuations which can be observed in the upper 100 m in the waters along the southern margin of the continental United States. The work of Fuglister (1946) shows a marked cooling of the surface waters of the northern Gulf of Mexico during the winter months. The 70°F isotherm (21.1°C) extends roughly along a line drawn from the Rio Grande to a point off the continental shelf from Tampa, then to the Florida Everglades, showing colder waters far from the coastal areas. Evidence of the large-scale winter cooling can also be observed from the data collected by the ATLANTIS during February and March 1947 in the northwest portion of the Gulf of Mexico (Phleger, 1951). The bathythermograms collected during the cruise illustrate the cooling occurring over the shelf and extending well offshore.

Data obtained on the same cruise indicate that a saline layer with values in excess of 36.5 ‰ was present over the entire area (ibid.), except in the immediate vicinity of the coast where the waters were influenced by run-off. The highly saline layer extended below 150-200 m at the offshore station, being restricted to bottom depths along the shelf. The effects of seasonal cooling were observed in the 1935 ATLANTIS stations in the eastern Gulf of Mexico also. Here again most of the salinities range between 36.2 ‰ and 36.5 ‰ at depths slightly in excess of 150 m. Surface salinities in excess of 36 ‰ and as high as 37.3 ‰ are also found on the shelf of the Florida west coast (Chew, 1955; Marine Laboratory, 1957).

The presence of waters having salinities between 36 and 36.7‰ with a probable average of about 36.3 ‰, suggests that when cooling occurs, surface waters in the northern and eastern Gulf of Mexico sink and seek their own density level. In this area, the temperature of the surface water is higher than 84°F (28.9°C) during the summer, and drops to about 68°F (20°C) in the winter.

Density values for waters of various salinities and temperatures corresponding to the range of observed values, are found in Table 2.

TABLE 2
DENSITIES

Salinity ‰	*Temperature °C*		
	18	*19*	*20*
36.0	26.05	25.82	25.55
36.2	26.20	25.97	25.70
36.4	26.36	26.11	25.86
36.6	26.51	26.28	26.00

If these σ_t values are compared with corresponding σ_t values for the Yucatan Water, it can be observed that the lowest σ_t of the 20°C column would seek its own density level at a depth of about 200 m in the Yucatan Water, while the highest σ_t would seek its own level between 200 and 300 m. These values correspond to the depths above which the Yucatan and Gulf of Mexico Waters are different. Thus the process of cooling saline surface layers along the offshore and near shore margins of the southern United States affords an explanation for the formation of new water masses in the Gulf.

The mechanisms governing the formation of the Continental Edge Water have not yet been fully investigated, but several inferences can be drawn at this stage. The Continental Edge Water appears to be intermediate between the Yucatan and Western Gulf Waters. It can be safely assumed that increase of salinity by evaporation and cooling of the surface layers of the original Yucatan Water are the main agents contributing to the formation of the Edge Water. The presence of the Yucatan Water in the eastern Gulf regulates the extent of formation of Edge Water to a large degree.

Under average conditions, the northern boundary of the Yucatan Water is found slightly south of the latitude of Tampa. This boundary is known to fluctuate north and south of its average position; such fluctuations are usually detected from properties of the water itself.

Two interpretations of the hydrographic conditions governing these fluctuations can be advanced. The first and most obvious one is that fluctuations in the intensity of water transport through the Yucatan Strait are reflected in fluctuations in the extent of ingress of Caribbean water into the Gulf. A second interpretation is that fluctuations in the intensity of evaporation and cooling of waters along the northern boundary of Caribbean water intrusion contribute to an accelerated transformation of the original Yucatan Water into Edge Water, which is reflected in an apparent shift of the northern boundary.

An examination of climatological data for the eastern Gulf of Mexico (Jacobs, 1951; Leipper, 1954) shows that the most favorable conditions for the formation of the Edge Water occur in fall, winter, and early spring. During these periods, the general air circulation over the area comes from the NNW-SSE sector, which tends to bring drier and cooler air, especially during the winter months. Such an atmospheric circulation creates temperature and hence vapor pressure differentials between the usually much warmer waters of the Yucatan and the air which are very favorable to active evaporation.

The intermediate appearance of the Edge Water can be explained as that of a transition stage between the Yucatan and Western Gulf Waters, since the Edge Water is too close to the original Caribbean source to have time to acquire all of the Western Gulf characteristics. The mixture of T-S characteristics observed in the eastern Gulf region can be a reflection of several stages in the gradual changes occurring in the original Yucatan Water.

The Edge Water formed along the northern and eastern edge of the Yucatan Water which cannot readily escape into the western Gulf of Mexico because of the general pattern of circulation is transported eastward and southward between the eastern edge of the Yucatan Water and the coastal shelf. Such water retains its intermediate character all along the continental edge of the current since it moves into regions where climatic changes are no longer effective in affecting its characteristics.

Some mixing probably occurs along the margins of the Yucatan Water. Such mixing also creates conditions for the modification of the original Yucatan Water which are reflected in some of the T-S characteristics observed along the margins. At present no differentiation can be made between the latter T-S curves and those of the Edge Water.

C. Straits of Florida

The identification of water masses in the Straits of Florida is based upon the study of T-S relationships from hydrographic data collected between the Florida Keys and Cuba, and between Miami and Bimini, since the largest amount of data is available for these areas. A few scattered observations are available for the remainder of the Straits.

1. *Southern Straits of Florida.* The T-S characteristics of the Southern Straits are represented by the data collected between Key West and Havana.

Two distinct water masses are present in the Southern Straits (Fig. 5A,B): the Yucatan Water and the Edge Water. Studies of the spatial distribution of T-S characteristics indicate that the boundary between the two water masses is usually found to be about one-half of the distance between the western portion of the Florida Keys and Cuba.

The general appearance of the Edge Water T-S curve is similar to the one described for the eastern Gulf of Mexico. The wider range in salinities in the T-S envelope, from about 36.1 ‰ to about 36.7 ‰, should be noted here. The greatest spread appears in depths

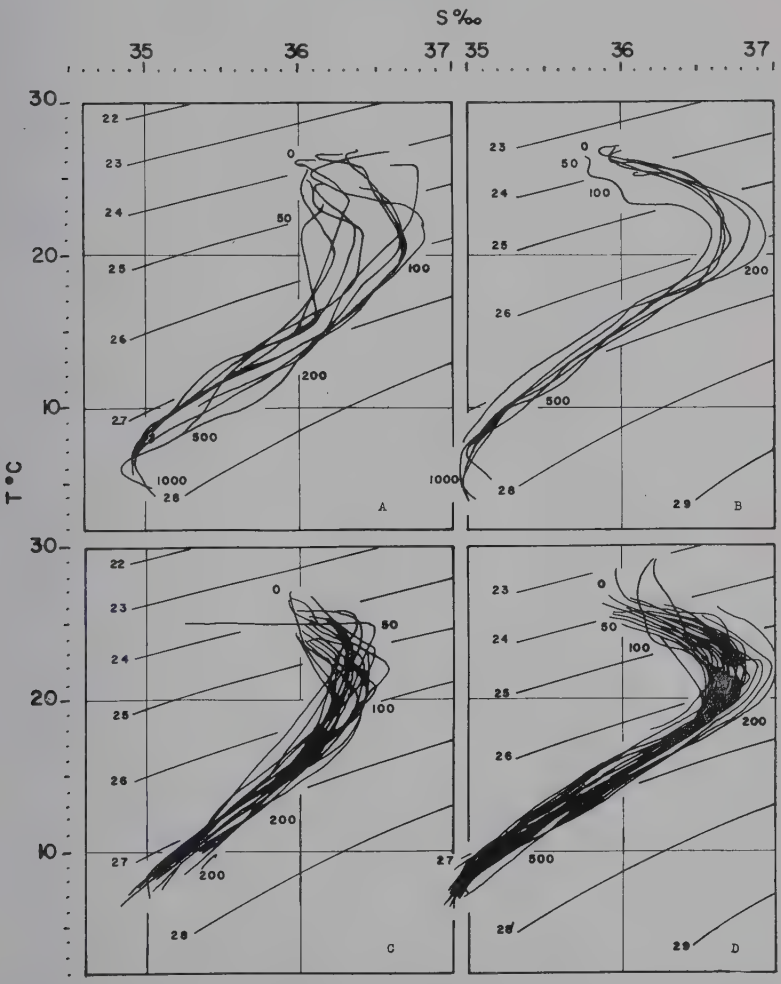

FIGURE 5. Temperature-Salinity relationships. Straits of Florida. Continental Edge Water: A, Southern Straits. C, Northern Straits. Yucatan Water: B, Southern Straits. D, Northern Straits.

shallower than 150 m. Some of the curves having the higher salinities between the surface and 150 m have many characteristics in common with those of the western Gulf. The salinity minimum is well-defined

for that portion of the Straits, occurring between 800 and 1000 m.

The T-S characteristics of the Yucatan Water are similar to the original description. The salinity maximum is well developed at about 200 m, the salinity minimum at about 1000 m.

2. *Cay Sal Region.* The area surrounding Cay Sal Bank is almost unsurveyed hydrographically. Although the previous discussion suggests that the water mass properties found between the Florida Keys and Cay Sal Bank are similar to those observed in the Southern Straits, the same cannot be said of Santaren, Nicholas, and Old Bahama Channels.

The meager temperature and salinity data available for these channels indicate that they represent a region of hydrographic transition between Western Atlantic waters and these found along the insular margin of the Straits of Florida. These channels will be discussed further in the section on dissolved oxygen.

3. *Northern Straits of Florida.* The T-S relationships for the section between Miami and Bimini, the only complete seasonal set of T-S curves available for the entire area, are shown in Fig. 5 C, D.

The Edge and Yucatan Waters are well-differentiated. The T-S envelope for the Edge Water is much narrower in the upper 150 m than the one observed previously in the Western Straits. Another notable feature of the Edge Water is the near absence of large temperature and salinity fluctuations at the surface. This is in sharp contrast to conditions observed in the Eastern Gulf. The salinity and temperature distributions of the water mass will be discussed below.

The Yucatan Water exhibits the same characteristics previously described. Very little fluctuation in surface temperatures occurs in depths shallower than 100 m. The most important difference between the T-S characteristics of the Yucatan Water of the Northern Straits and those of the areas discussed previously is the disappearance of the salinity minimum. This reflects the effect of the bathymetry which prevents intrusion of water from depths greater than about 800 m into this section of the Straits of Florida. No salinity minimum is observed for the Edge Water.

The boundary between the Edge and Yucatan Water in the Northern Straits of Florida is found to lie between 10 to 15 miles from the east coast of the Florida peninsula, which is about 1/3 of the distance between Miami and Bimini.

4. *Cross-channel distribution of T-S relationships in the Straits of*

Florida. Hydrographic observations made at five anchor stations between Fowey Rocks and Gun Cay by A. E. Parr from the R/V ATLANTIS in April 1937 (Parr, 1938) provide the basis for a better interpretation of the distribution of water masses in the Straits of Florida. Each anchor station was occupied for 24 hours, with hydrocasts taken approximately every two hours.

a. Stations 2857 and 2858, on the Bimini side of the Straits, exhibit a very pronounced salinity maximum, about 36.8 ‰ between 100 and 200 m, characteristic of the Yucatan Water in that portion of the Straits (Fig. 6).

b. Station 2854, about 5 miles off the east coast of Florida, has the T-S characteristics of the Edge Water, with no salinity maximum, the water being nearly isohaline at about 36 ‰ to a depth a little over 100 m.

c. Stations 2855 and 2856, located approximately 10 and 20 miles from the east coast of Florida, exhibit marked salinity variations between 50 and 200 m. Our present knowledge of the behavior of the current in the Straits indicates that these two stations lie near the axis of the Florida Current and therefore the salinity variations observed at these stations may be explained by the meanderings of the boundary between the Edge and Yucatan Waters, suggesting that these two stations lie in a transitional zone between the two waters.

The results of Parr's work indicate that a well-defined cross-channel distribution of the T-S characteristics is observed in the Straits and that care should be taken in interpreting salinity fluctuations. The location of the sampling stations with respect to the position of the boundary between the Edge and Yucatan Waters must be considered. Because of the change in the spatial distribution of the boundary with respect to time, the samples from stations 2855 and 2856 could have been influenced by either Edge or Yucatan Waters.

Parr's observations dealt only with the short term distribution of temperature and salinity. In order to determine whether the previous pattern of cross channel distribution of T-S relationships is a transient or permanent feature, all the available hydrographic data, collected by The Marine Laboratory in nearly every month between April 1955 and November 1956, were analyzed.

The hydrographic stations from which the data were assembled almost duplicate Parr's stations, hence it was possible to compare all of the data and construct an annual pattern.

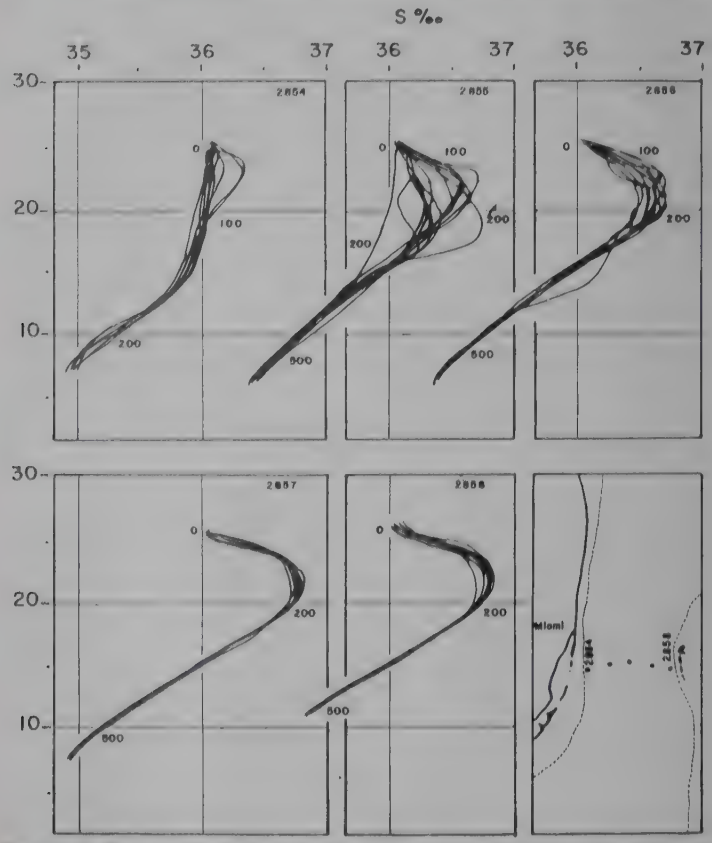

FIGURE 6. Temperature-Salinity relationships, Miami-Bimini, Atlantis anchor stations 2854 - 2858, April 17th-23rd 1937.

The analysis showed that the cross-channel pattern of distribution of T-S relationships is retained throughout the year (Fig. 7). This pattern is a permanent feature, the continental margin of the Florida Current being characterized by the Edge Water, the insular margin by the Yucatan Water, and the boundary between the two waters meandering within the transition zone.

Each station was studied to determine the extent of seasonal vari-

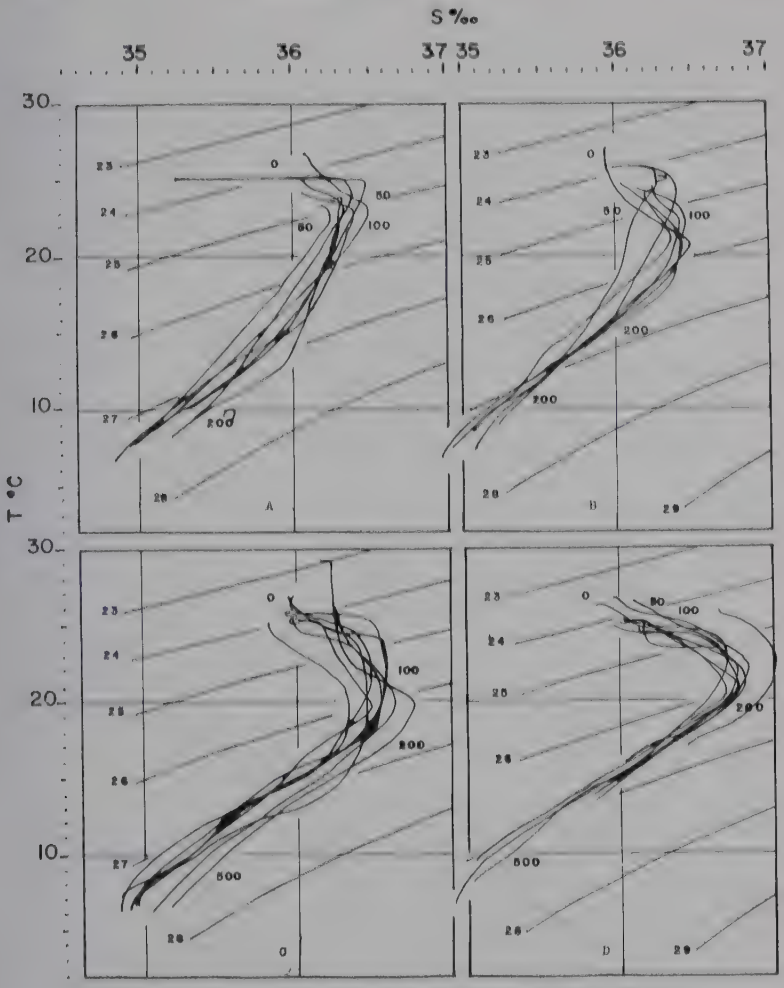

FIGURE 7. Temperature-Salinity relationships. Miami-Bimini: A, 5 miles. B, 10 miles. C, 20 miles. D, 40 miles.

ability. The T-S curves at the stations located along the insular margin of the Florida Current do not exactly duplicate each other, but form a well-defined envelope. The spread of the envelope for the stations off Bimini appears to reflect mainly salinity variations rather than

variations in temperature. The greatest variations are observed in the vicinity of the salinity maximum, with a spread of about 0.5 ‰. Seasonal fluctuations in the heat content of the water at these stations show some seasonal warming and cooling of the waters from the surface to about 150 m, causing the T-S curve to rotate slightly around this point. The seasonal temperature range is between 25°C and 28°C (Bsharah, 1957).

Examination of the data of the station located near the east coast of Florida reveals marked fluctuations in both temperature and salinities. Surface salinities at the station closest to Miami will sometimes be as low as 33 ‰, although generally the salinities are mostly between 36.1 ‰ and 36.2 ‰, increasing to about 36.5 ‰ at 50 m. Temperature fluctuations are rather large, especially between 50 and 100 m, ranging from about 13°C to 23°C. It is interesting to note here that the highest temperatures were observed at stations occupied in November, December and January. At that time the water was nearly isohaline at 36.2 ‰ and 36.5 ‰ between 30 and 100 m. No well defined seasonal temperature fluctuations could be established for this station (ibid).

At this time one can state only that salinity and temperature fluctuations occur at every station across the Straits of Florida and although temperature fluctuations are seasonal at certain stations, no statement can be yet made concerning the nature of the salinity fluctuations.

D. Northern Approaches to Straits of Florida and Bahamas

In order to obtain continuity in the interpretation of the distribution of the water mass characteristics of the Straits of Florida, the outflow of the Straits was investigated as far north as the latitude of Jacksonville. The area between Cape Hatteras and the northern Bahamas has been little investigated hydrographically. The only available data are those collected by the ATLANTIS in 1933 and by the THEODORE N. GILL in 1952-1953 (Table 1). The latter, although not completely published, are still the only seasonal observations of hydrographic conditions in the area.

1. *Northern approaches to the Straits of Florida.* The T-S relationships for the waters of the northern approaches to the Straits of Florida are illustrated in Figure 8 A,B. The Yucatan Water retains most of its characteristics as far north as the latitude of Jacksonville. A new water mass intrudes in the Yucatan Water as demonstrated

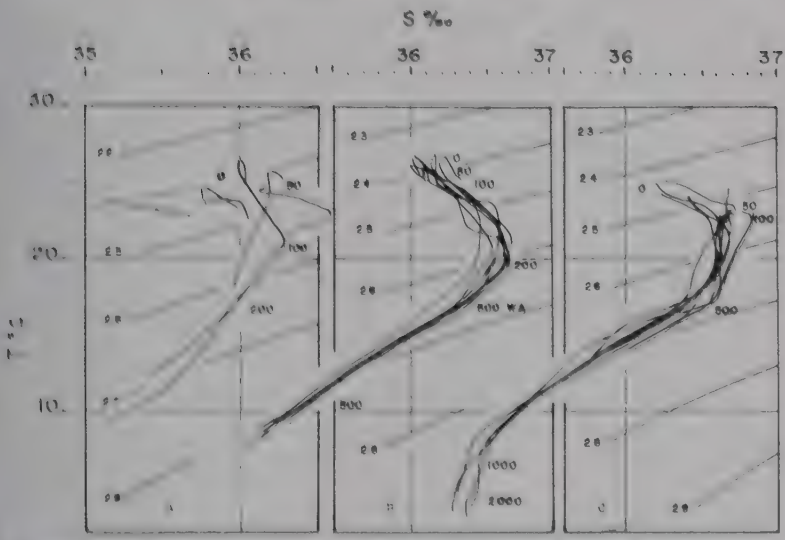

FIGURE 8 Temperature-Salinity relationships, Northern Approaches to Straits of Florida and Bahamas. A, Continental Edge Water. B, Yucatan Water. C, Bahamas.

from σ_t changes at the 500 m level. The T-S curves of this new water have the same shape and fall within the same envelope as those of the Yucatan Water. However, the depth levels of σ_t values change markedly and can be traced directly to the western Sargasso Sea water mass.

The Edge Water appears to become considerably modified after it leaves the Straits, but too little information is presently available to follow the changes.

The salinity minimum is again absent from the T-S curves of the stations occupied on Blake Plateau. The average depth of the plateau prevents intrusion of Atlantic waters deeper than about 800 m.

2 Bahamas. The T-S relationships for the Bahamian waters immediately adjacent to the Straits of Florida are illustrated in Fig. 8C. The waters of the Bahamas belong to the western Sargasso Sea. Marked seasonal temperature variations occur between the surface and about 200 m at the stations in the eastern section of Northeast Providence Channel. February temperatures of the surface waters are between 24°C and 25°C; October temperatures in the vicinity of

29°C. The seasonal range of fluctuations in temperature is between 2°C and 3°C for the upper 100 m. Salinity values remain nearly constant.

Section IV. Distribution of Dissolved Oxygen

The oxygen-density relationships enable the oceanographer to identify water masses of various origins more easily and become a very useful tool when many ambiguities are found in the classification of T-S relationships.

Density values afford better means of correlation when comparing the oxygen values at different locations than do other variables (Richards, 1955). Surfaces of equal density are of approximately constant potential density, thus identifying the paths of free movement by lateral mixing or flow. Density values increase with depth. Thus, many uncertainties as to the identification of the layer at which the sample was collected are removed. Also, the density of a given layer will fluctuate very little in deeper water. Surface density variations are greater, but still remain within narrow limits. The distribution of dissolved oxygen in the area under investigation was made by analyzing the oxygen-density relationships.

A. Yucatan Straits

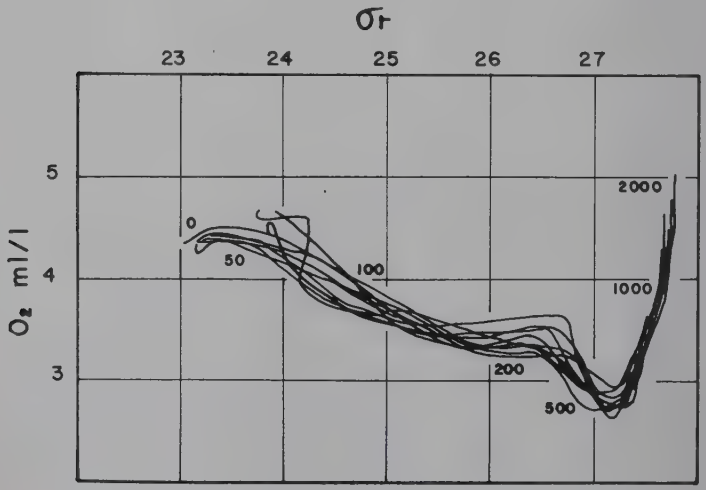

Figure 9. Oxygen-Density relationships. Yucatan Strait.

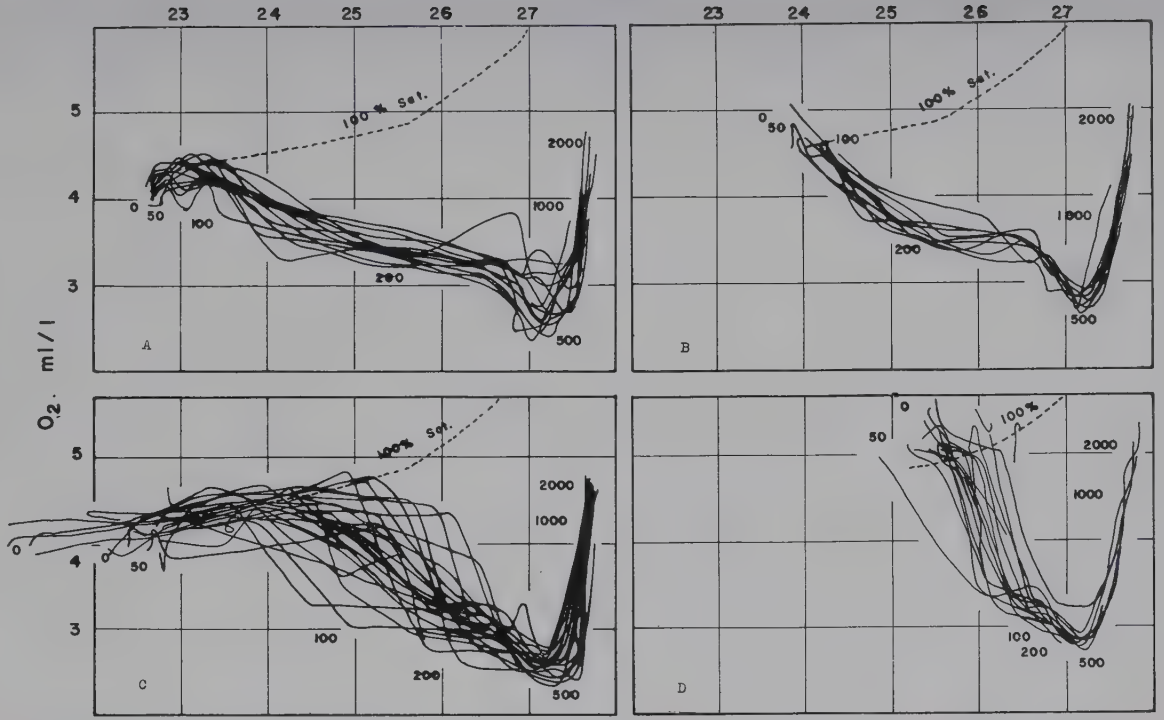

FIGURE 10. Oxygen Density relationships. Straits of Florida. Yucatan Water: A, Summer. B, Winter. Continental Edge Water: C, Summer. D. Winter.

The oxygen-density relationships for the Yucatan Straits are illustrated in Fig. 9, and exhibit the following characteristics which define the oxygen distribution of the Yucatan Water:

1. The oxygen values for the waters between the surface and 100 m are about 4.5 ml/l, grouping within a very narrow range of σ_t. Between σ_t 23 to about 26.5 (about 300 m), there is a nearly linear decrease in oxygen from 4.5 ml/l to about 3.5 ml/l.

2. Between σ_t 26.5 and 27.1, there is a sharper decrease, giving a little knee to the curve.

3. An oxygen minimum of about 2.7 ml/l is present at about σ_t 27.3 corresponding to depths ranging between 450 and 600 m.

4. From σ_t 27.3 to 27.8, the oxygen increases sharply, reaching a maximum value slightly in excess of 5 ml/l at depths a little over 2000 m.

B. Eastern Gulf of Mexico

The distribution of dissolved oxygen in the eastern Gulf of Mexico can be characterized from the data collected by the R/V ATLANTIS in March-April 1935 (Table 1), and by Texas A. & M. in August-September 1954 (ibid). These data are the only ones available and were collected 20 years apart, hence some reservations should be made when comparing absolute values.

The sorting out of various oxygen-density relationships was based upon the sorting of the corresponding T-S relationships (Fig. 10). Marked differentiations can be observed between the oxygen-density relationships of the Edge and Yucatan Waters.

1. *Yucatan Water.* The Yucatan Water retains essentially the same oxygen-density characteristics observed in the Yucatan Strait. Seasonal effects become noticeable, affecting only the upper 150 m. There is slight lowering of the oxygen content in the upper 100 m during the warmer months. The fluctuations in the oxygen content of the water are directly related to the change in the solvent capacities of the water, following seasonal temperature fluctuations as shown by the trends of the 100% saturation curves.

2. *Continental Edge Water.* The oxygen-density relationships of the Edge Water differ markedly from those of the Yucatan Water. The biggest differences occur in the upper 300 m, where seasonal effects are more drastically exhibited.

During the cooler period, the waters between the surface and 150

m have σ_t between 25 and 26, and the oxygen content of the upper 50 m is in excess of 5 ml/l.

During the warmer period, the increase of temperature and some lowering of salt content stretches the curve towards σ_t values as low as 22 for the upper 50 m or so, and the oxygen content decreases to about 4.2 to 4.5 ml/l. This decrease is again governed primarily by the temperature increase affecting the solvent capacity of the water, as indicated by the trend of the 100% saturation curves.

The greatest differentiation between the oxygen content of the Edge and Yucatan Waters is observed when comparing the values between the 50 and 200 m levels of both waters, corresponding to σ_t 24 to 26.8. There is a considerable decrease in the oxygen content of the 100 m level of the Edge Water as compared with the Yucatan Water. The oxygen decreases from about 4.3 ml/l in the Yucatan Water to about 3 ml/l in the Edge Water. The 200 m level of the Yucatan Water has oxygen values of about 3.5 ml/l; oxygen values for the same level in the Edge Water are a little less than 3 ml/l. Below about 300 m (σ_t26.8) the oxygen-density curves of both waters merge into a single envelope from σ_t 26.8 to 27.6.

The differences between the oxygen content in the upper 300 m of the Edge Water as compared to Yucatan Water adds to the argument that the Edge Water is a new water mass formed in the northern Gulf and that the identity of the Edge Water can be ascertained from both T-S and oxygen-density relationships.

Another interesting feature of the oxygen-density relationships of the Edge Water is the wide spread of the oxygen-density envelope between 50 and 100 m as compared to the narrow envelope of the Yucatan Water. This points up the difficulties and limitations of identifying the two water masses from T-S relationships alone. Some of the oxygen-density curves could probably be superimposed upon more typical Yucatan curves. The wide range of the oxygen-density envelope of the Edge Water reflects variations similar to those observed in the T-S relationships. Studies should be conducted to sort the data further and more refinement in the analysis of the data is necessary.

C. Straits of Florida

The distribution of oxygen in the Straits of Florida is also based primarily on data collected between the Florida Keys and Cuba and between Miami and Bimini.

1. *Southern Straits.* Unfortunately few oxygen data are available for

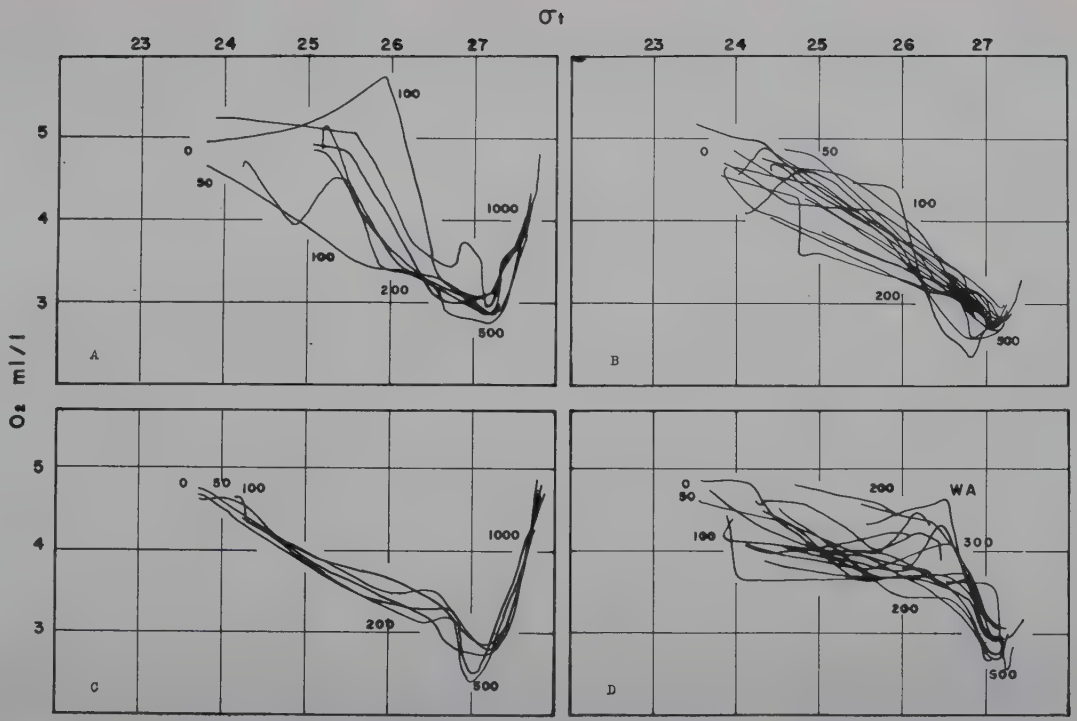

FIGURE 11. Oxygen-Density relationships. Straits of Florida. Continental Edge Water: A, Southern Straits. B, Northern Straits. Yucatan Water: C, Southern Straits. D, Northern Straits. Yucatan and Western Atlantic Water.

this region. The oxygen-density relationships, illustrated in Fig. 11 A,C, indicate a marked separation between the oxygen distribution of the Yucatan and Edge Waters. The oxygen-density curves of the Yucatan Water group fall within a narrow envelope similar to that of the original Yucatan.

The oxygen-density relationships of the Edge Water show many similarities to the ones observed in the eastern Gulf. The envelope of the curves spreads over a wide range of oxygen values between 50 and 150 m. Below about 300 m (σ_t 26.9 to 27) all the curves merge within a very narrow envelope which cannot be differentiated from the original Yucatan.

An oxygen minimum of about 2.8 ml/l is observed at σ_t 27.2, corresponding to about 500 m. From σ_t 27.2 to about 27.9, the oxygen content of the water increases sharply from the minimum to a little in excess of 5 ml/l at about 1800 meters.

2. *Northern Straits.* The oxygen-density relationships of the Northern Straits are illustrated in Fig. 11 B,D. The most noticeable difference between the oxygen-density relationships of the Southern and Northern Straits is the marked change in the oxygen distribution of the latter.

a. The majority of the curves show a nearly linear decrease in oxygen between σ_t 24 and 27.2, from about 4.7 ml/l to 2.8 ml/l.

b. An oxygen minimum of about 2.8 ml/l is observed at σ_t 27.2. This oxygen minimum is found at 500 m in the eastern portion of the Straits, shallowing to about 200 m on the western side in accordance with the warping of the σ_t surfaces across the channel.

c. Below the depth of the oxygen minimum, the oxygen-density curve rises sharply but is very short. It never reaches the high values found in the eastern Gulf and Southern Straits. The near absence of the larger oxygen values beyond the oxygen minimum illustrates the effects of the topographic sill existing between the Gulf of Mexico and the Atlantic Ocean which prevents intrusion of waters deeper than about 800 m. This supports the interpretation drawn from T-S relationships.

d. Oxygen-density relationships at sampling stations nearest to Bimini show that a new water mass is intruding in that portion of the Straits. The oxygen-density curves exhibit oxygen values in excess of 4 ml/l corresponding to depths greater than 300 m (σ_t 26.9). These "anomalous" oxygen-density curves positively identify the intrusion

of Western Atlantic Water in the Straits of Florida. Such intrusion, however, is restricted to the immediate vicinity of the Bahama Banks; it is not a permanent feature but is observed at least 50% of the time.

It is interesting to note that the intrusion of Western Atlantic Water does not appear to extend to the bottom of the Straits. The probable reason lies in the presence of an underwater spur less than 300 fathoms deep extending from the western tip of the Great Bahama Bank northwestward past the southern margin of the Little Bahama Bank, thus isolating portions of the deeper waters between the Straits of Florida and Northwest Providence Channel. The depth of the spur appears to average about 250 fathoms (450 m) which would roughly correlate with the maximum depths at which the intrusion of Western Atlantic Water can be detected.

e. A marked change also occurs in the oxygen distribution of the Edge Water. The oxygen-density relationships indicate that there is a net gain in oxygen between 50 and 200 m. The oxygen-density curves for the Edge Water have many more similarities with those of the Yucatan Water so that no clear-cut separation can be made. No cross-channel differentiation between the oxygen-density curves are observed.

3. *Miscellaneous Observations.* Few other oxygen data are available. Oxygen values observed in Santaren, Nicholas and the western portion of the Old Bahama Channels indicate that the oxygen-density relationships of the latter have all the characteristics of Western Atlantic Water. Nicholas channel appears to be more under the direct influence of waters originating from the Straits of Florida proper, while in Santaren Channel, a tongue of more typically Western Atlantic Water appears along the Bahama Bank.

Hydrographic stations occupied between West Palm Beach and Settlement Point indicate that the oxygen-density distribution follows the pattern observed between Miami and Bimini. The Western Atlantic Water is also intruding along the edges of the Little Bahama Bank.

D. Northern Approaches to Straits of Florida and Bahamas

The waters leaving the Straits of Florida come into immediate contact with these of the western Atlantic Ocean.

1. *Jacksonville to Northern Straits of Florida.* The oxygen-density relationships for the sampling stations situated between Jacksonville and the northern entrance to the Straits of Florida, show the im-

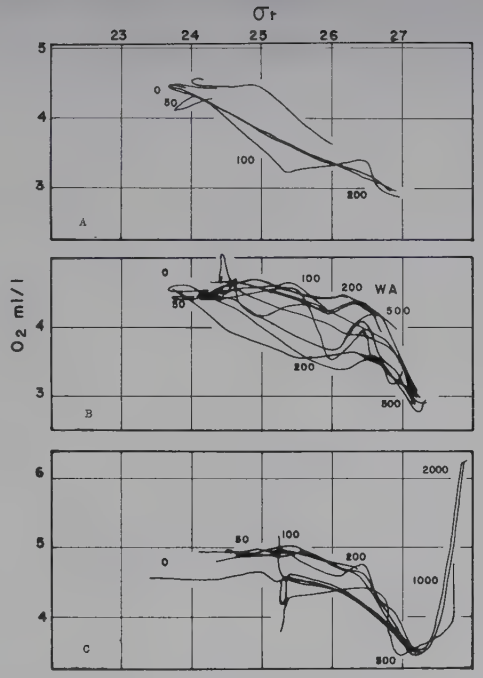

FIGURE 12. Oxygen-Density relationships, Northern Approaches to Straits of Florida, Bahamas. A, Continental Edge Water. B, Yucatan and Western Atlantic Waters. C, Bahamas.

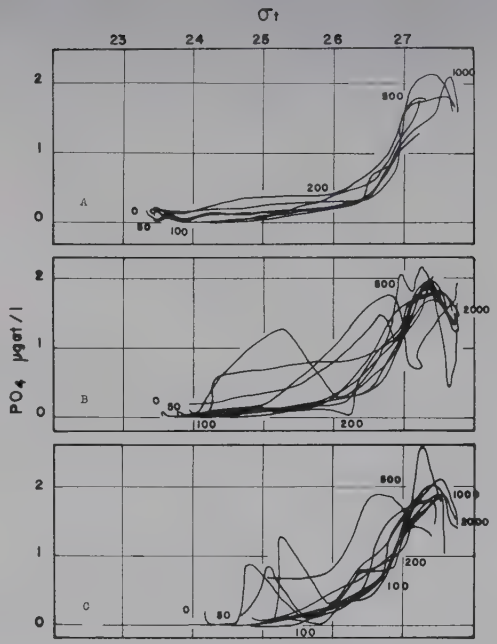

FIGURE 13. Phosphate-Density relationships. A, Yucatan Strait. Eastern Gulf of Mexico: B, Continental Edge Water. C, Yucatan Water.

mediate influence of intrusion of Atlantic water into the Florida Current (Fig. 12 A,B).

The appearance of Atlantic water is already very noticeable from THEODORE N. GILL stations taken off Jupiter Inlet, in the northern Straits (Table 1). More and more Atlantic water is quickly added to the current as it flows northward. Present data indicate that typical oxygen-density relationships of the Western Atlantic Water-mass are present at all the stations east of meridian 79°30′ W, south of Jacksonville. This indicates that Western Atlantic Water is found as a permanent feature slightly west of the line corresponding to the average position of the Gulf Stream as indicated on navigational charts.

It is hoped that a more comprehensive description of the hydrography of the region can be made when all of the T. N. GILL data become available.

2. *Bahamas*. The oxygen-density relationships of stations in eastern Northeast Providence Channel and off Elbow Cay are illustrated in Fig. 12 C. The oxygen distribution at these stations indicates pure Western Atlantic Waters.

Section V. Distribution of Dissolved Inorganic Phosphate

A comprehensive analysis of the distribution of dissolved inorganic phosphate (PO_4-P) for the area under investigation is very difficult at present since the phosphate data are the poorest of all. Very few hydrographic investigations included phosphates in their samplings. The present data lack continuity and are extremely scattered. Very few hydrographic stations have simultaneous temperature, salinity, oxygen, and phosphate values available for correlation.

The phosphate data were analyzed by means of phosphate-density relationships. It is found that by treating the data in this manner, the same arguments can be advanced as previously stated in section IV. The time between samplings becomes less important and a general pattern of distribution of phosphate with depth can be established.

A. Yucatan Channel

The phosphate-density distributions for the Yucatan Strait are illustrated in Fig. 13 A.

Although the above data are the only ones published for the Yucatan Strait, the general shape of the phosphate-density curve can be regarded as representative of the phosphate distribution in that area, since only the magnitude of some of the phosphate values will probably vary.

B. Eastern Gulf of Mexico

The phosphate-density relationships for the eastern Gulf of Mexico are based solely on the data collected by Texas A. & M., cruise 4 - 2A, January 1952 (Table 1).

The phosphate-density curves were sorted out on the basis of their corresponding T-S curves; the results are illustrated in Fig. 13 B,C. It is very difficult, for the present, to advance any arguments about the distribution of inorganic phosphate in the eastern Gulf of Mexico as data are nearly lacking.

The phosphate-density relationships of the Texas A. & M. cruise (ibid.) exhibit a wide variation in phosphate content. No argument can be advanced at present as to the significance of these variations, since more sampling is necessary to determine if these variations are real. If the higher phosphate values detected in the upper layers of the Edge Water can be observed in future surveys, a balance sheet must be established to determine the source of the phosphate increase. To date no such investigation has been undertaken, hence no interpretation of phosphate distribution in the eastern Gulf of Mexico will be made here.

C. Straits of Florida

The distribution of dissolved inorganic phosphate in the Straits of Florida is inferred from data collected in the Southern and Northern Straits.

1. *Southern Straits.* The phosphate-density relationships for the Southern Straits of Florida are illustrated in Figure 14 A, C.

The general trend of both sets of curves is the same. A well-defined phosphate maximum is observed between 600 and 900 m. The most noticeable difference in the phosphate content between the two waters lies in an apparent increase in the phosphate content of the Edge Water between 50 and 200 m. Such an increase was also observed in the eastern Gulf.

No arguments will be advanced at this time as to the exact significance in the increase of phosphate in the upper layers of the Edge Water. The present data are not sufficient to substantiate inferences as to the mechanisms involved. Further studies and more sampling will be necessary.

2. *Cay Sal Region.* No phosphate data are available for this region.

3. *Northern Straits.* The distribution of dissolved phosphate between

FIGURE 14. Phosphate-Density relationships, Straits of Florida. Continental Edge Water: A, Southern Straits. B, Northern Straits. Yucatan Water: C, Southern Straits. D, Northern Straits.

Miami and Bimini is a little better known. The general pattern of phosphate-density distribution in the Miami-Bimini section is illustrated in Fig. 14 B,D.

The general trend of both sets of curve is the same. The highest phosphate values are found at the bottom, but no decrease of phosphate is observed past the maximum. This dramatically illustrates the effects of sill depth and gives a positive proof that no water deeper than 800 m intrudes in the Straits.

A marked difference between the phosphate content of the Edge and Yucatan Waters is observed between 50 and 200 m. The Edge Water appears to have higher phosphate values for these depths. While no arguments will be advanced at this time as to the processes involved and the significance of such increase, one should note that the phosphate distribution observed between the two waters of the Miami-Bimini section has many similarities to the characteristics observed between Key West and Havana (Southern Straits).

4. *Miscellaneous Studies.* Some seasonal studies of the phosphate distribution between Miami and Bimini are available from data collected by The Marine Laboratory in 1950-1952 and 1954-1955 (Table 1).

a. 10 *mile station.*

The term "10 mile station" refers to a sampling station located 10 miles east of the Miami sea buoy. The phosphate data for that station span a little over two years of samplings (Miller *et al.,* 1953).

If the distribution of phosphate with depth is plotted for every month for the entire survey, a fluctuation of the distribution of phosphate is observed (Fig. 15). If the same procedure is followed for the density values, a similar fluctuation is observed.

Before attributing any seasonal significance to the phosphate fluctuations, the location of 10-miles station with respect to the boundary between the Edge and Yucatan Water must be taken into account. The station is located within the transition zone. The diagrams show that the phosphate fluctuations follow exactly the density fluctuations. The fluctuations of phosphate with respect to depth can thus be attributed to a chance sampling of either water as the boundary between the two water masses meanders past the station, and cannot be regarded as seasonal only.

b. 40-*mile station.*

The term "40-mile station" refers to a sampling station located

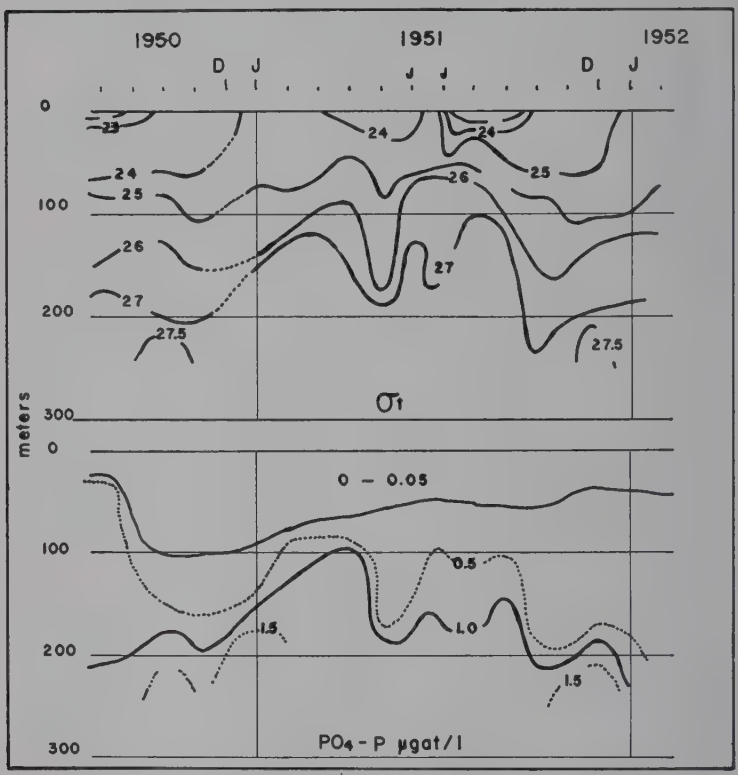

FIGURE 15. Phosphate and Density distributions, 10 mile station.

approximately four miles west of Gun Cay (Great Bahama Bank), 40 miles ESE of Miami sea buoy.

The phosphate data available for that station are fewer than for the 10-mile station. The data show (Bsharah, 1957) the increase of phosphate from the surface to the bottom, the highest values being found at the greatest depth. The absolute values of the bottom phosphates are still a matter of conjecture, and confirmation is needed for values as high as 2.6 μ gat/1. Recent unpublished data seem to indicate that maximal values are probably more in the vicinity of 2 μ gat/1, which would be more in agreement with values observed in the Atlantic and Caribbean.

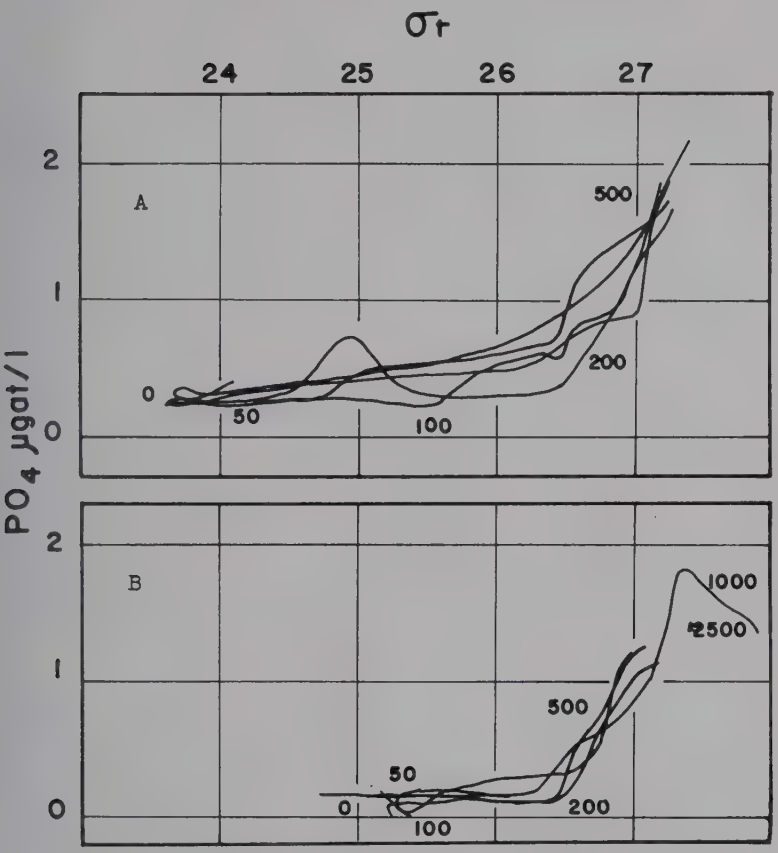

FIGURE 16. Phosphate-Density relationships. A, Northern Approaches to Straits of Florida. B, Bahamas.

The phosphate data for the 40-mile station are too fragmentary to allow any interpretation as to seasonal fluctuations. It must be remembered that the 40-mile station is often influenced by instrusion of Western Atlantic Water. Hence some of the argument offered for the 10-mile station will also apply here before any inferences can be made to seasonal distribution of phosphate with depth.

D. Northern Approaches to Straits of Florida and Bahama

The distribution of phosphate in the area between the northern

entrance to the Straits of Florida and Jacksonville is illustrated by the phosphate-density relationship of Figure 16 A.

The shape of the curve remains essentially the same as previously observed in the Straits of Florida and other areas. The phosphate maximum is again absent because the depth of Blake Plateau prevents the intrusion of any water deeper than 800 m. The bottom depth of Blake Plateau lies exactly in the region of the phosphate maximum.

The phosphate-density relationships for Bahamian waters are illustrated in Figure 16 B. The shape of the curve follows the same trend, but the phosphate maximum appears to occur a little deeper, between 900 and 1000 m.

Discussion and Summary

The identification and distribution of water mass properties of Yucatan Strait, eastern Gulf of Mexico, Straits of Florida, western Atlantic Ocean and portions of the Bahamas is based upon the analysis of temperature-salinity, oxygen-density and phosphate-density relationships.

The temperature-salinity relationships were used as the primary means of identifying the various water masses, the other parameters being directly correlated to the spatial distribution of the T-S relationships.

The source water for the Gulf of Mexico and portions of the Straits of Florida comes from the Caribbean through Yucatan Strait. As the Caribbean water penetrates as a core into the eastern Gulf of Mexico, it moves into a region of climatic transition and comes into contact with new water masses formed in the Gulf, the Western Gulf Water and Continental Edge Water. The differentiation between the last two waters and the original Caribbean water is best observed from a change in the temperature-salinity relationships in the upper 300 m.

The new water masses observed in the Gulf of Mexico are formed from evaporation and cooling occurring in the offshore and nearshore waters along the southern margin of the United States. The salinity increase observed in the upper layers of the western and northern Gulf probably originates from active evaporation occurring during the fall, winter, and early spring when cooler, drier air sweeps over the greatest portion of the northern Gulf. Active sinking of the saline water takes place during the winter months when cooling is at a maximum.

The Continental Edge Water is found mostly along the northern and eastern edge of the Yucatan Water as a water mass of intermediate characteristics between those of the western Gulf and Yucatan. The Edge Water is certainly formed at the northern portion of the Yucatan Water where the water moves into an area where evaporation, cooling, and mixing along the boundary modify the original Caribbean water.

The prevalent circulatory pattern of the eastern Gulf helps the Continental Edge Water maintain its intermediate characteristics. The general circulation hampers free outflow of Edge Water into the western Gulf, the main transport carrying it eastward and southward, between the eastern margin of the Yucatan Water and the shelf of western Florida, thus removing it from the area where climatic changes could modify it further. The characteristic of the water mass observed in the western Gulf represents the new hydrographic equilibrium after the original Caribbean water has passed through the intermediate Continental Edge Water stage.

The Yucatan Waters flowing along the insular margin and the Edge Water observed along the continental margin of the Florida Current retain many of their characteristics as they flow through the Straits of Florida, and retain some of their identity north of the Straits.

The various water masses, first identified in the Gulf of Mexico and portions of the Straits of Florida on the basis of temperature-salinity relationships, can also be identified from corresponding oxygen-density relationships.

A marked differentiation in the oxygen characteristics between the Yucatan and Edge Water is observed in the eastern Gulf of Mexico. Oxygen values in the upper 200 m of the Edge Water are usually significantly higher, especially during the colder months when the holding capacity of the water for the dissolved gas increases with a sharp decrease in the water temperature. The general pattern of distribution of dissolved oxygen in the eastern Gulf of Mexico follows the pattern established from temperature-salinity relationships.

In the southern Straits, the oxygen distribution follows the pattern observed in the eastern Gulf. As the waters progress towards the northern Straits, the distributions of oxygen in the two water masses are more similar in the vicinity of the Miami-Bimini section.

A third water mass is found in the northern Straits of Florida. The appearance of Western Atlantic Water is readily detected from higher

oxygen concentrations between the surface and about 400 m. Deeper intrusion of Atlantic water is restricted by the bottom topography of the western portion of Northwest Providence Channel. The intrusion of Atlantic water was observed in at least 50% of the samplings off Bimini, being restricted to a narrow band along the Great Bahama Bank. Some of the Western Atlantic Water is also found in Santaren Channel from which it might be inferred that a band of Western Atlantic Water may extend along the entire length of the western edge of the Great Bahama Bank.

The distribution of oxygen in the area under investigation can be directly correlated to the patterns of distribution observed in the Caribbean and western Atlantic. The minimum oxygen values observed in the Straits of Florida are between 2.8 and 3 ml/1. These values, when compared to the data of Seiwell (1938) and Dietrich (1939), show that they are identical to the values existing in the southern and western Caribbean with the exception of the area between Hispaniola, Jamaica, and Cuba where the influx of Atlantic water is reflected in higher values of the oxygen minimum (between 3.0 and 3.4 ml/1).

Some of the water of Caribbean origin can be traced to an as yet undetermined latitude north of the Straits of Florida by its lower oxygen minimum values. Present data, however, indicate that a very rapid addition of Atlantic water to the water emerging from the Straits occur beginning as far south as the latitude of Vero Beach (27°35N). The same data show that the influence of the addition of Western Atlantic Water to the Florida Current is not detected from T-S relationships until about the latitude of Cape Canaveral (28°30 N). It is hoped that when all of the results of the THEODORE N. GILL cruises are published, a more complete study can be made on the intensity and fluctuations in the intermixing of the various waters north of the Straits of Florida.

The waters of the Bahamas are essentially of western Atlantic origin, as shown from their temperature-salinity and oxygen-density relationships

The distribution of dissolved inorganic phosphate is more difficult to analyze because of the scarcity and unreliability of the data. The present results indicate that phosphate-density relationships are essentially identical for all of the water masses of the area. Phosphate values from the surface down to about 200 m are low, usually less than 0.5μgat 1. From 300 to about 800 m the phosphate concentra-

tion increases rapidly reaching a maximum a little in excess of 2μ gat/l at 800 m in the Gulf of Mexico and Straits of Florida, deepening to about 900 m in the western Sargasso Sea.

The depths at which the phosphate maximum is observed in the Gulf of Mexico and Straits of Florida correspond to the depths at which the phosphate maximum is observed in the Caribbean region. The range in the magnitudes of the phosphate concentrations in the maximum still needs clarification and further investigation. The work of Rakestraw and Smith (1937) indicates a high phosphate source on the Caribbean side of the Lesser Antilles; some values are as high as 2.7 gat/l. The highest values reported between Hispaniola and Colombia were about 2.2 to 2.4μgat/l in the phosphate maximum between 700 and 900 m (ibid.). At present no confirmation can be advanced for similar values in the Straits of Florida. Better and more careful sampling is still necessary.

A pronounced cross-channel change in the depths of the oxygen minimum and phosphate maximum is observed in the Straits of Florida. As the waters progress through the Straits, the surface of equal density tilt and warp in accordance with the balance of hydrodynamic forces in the Straits. With the warping of the equal density surfaces there is an equivalent warping of the distribution with depths of other water mass properties, thus bringing the oxygen minimum and phosphate maximum closer to the surface on the Florida side of the Straits (Fig. 17).

The temperature-salinity, oxygen-density, and phosphate-density relationships clearly indicate that the Straits of Florida and Blake Plateau form an extensive sill separating the water deeper than 800 m of the Gulf of Mexico from the water of the Atlantic Ocean and vice versa. The sill depth is slightly deeper than the average depth of the oxygen minimum, being exactly within the average depth of the phosphate maximum (Fig. 18).

The influence of the bathymetry upon the hydrography of the Straits of Florida needs to be investigated further. The waters originating from the Gulf of Mexico experience a differential direction of flow at various depths as they follow the channel contours in the Straits. The waters shallower than about 350 m can flow freely over the Florida Key Bank. Water deeper than about 400 m must follow the deeper channel, being forced to a more northeasterly direction up to about 40 miles south of Miami where the deeper portion of the channel has a more north-south direction.

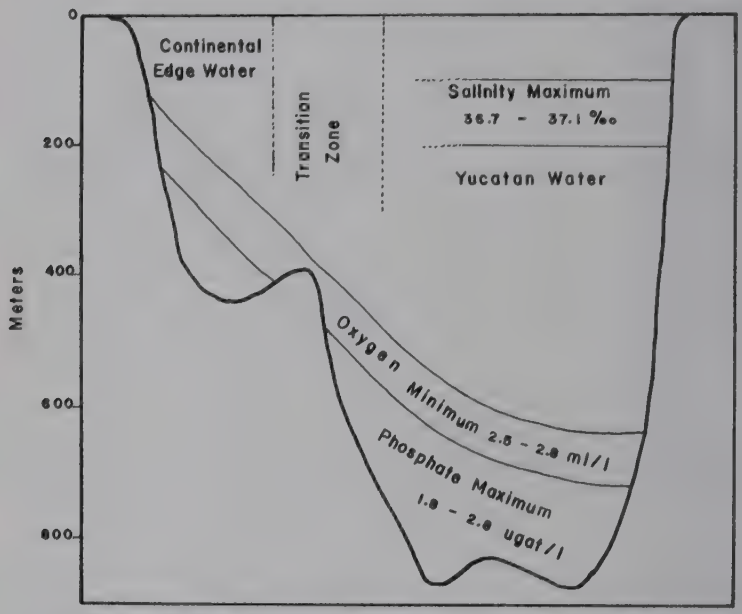

FIGURE 17. Cross channel distribution of water mass properties between Miami and Bimini.

The work of Pillbury (op. cit.) and Wüst (op. cit.) as well as observations obtained by The Marine Laboratory show that velocities of about 1 knot can be expected at about 200 m between Key West and Havana, deepening to about 300-400 m between Miami and Bimini. About 75 to 80 per cent of the total volume transport of the Florida Current can be assumed to take place in the upper 300 m between the Cay Sal Bank-Florida Keys and Miami-Bimini sections. Hence a fairly high velocity stream can be expected to flow over most of the Florida Keys Bank as shown by the approximate location of the axis of the Florida Current. As the deeper water will be channeled along a different axis of flow in the same area, divergent conditions may be expected within the internal structure of the current. The possibility that the differential flow created by the bathymetric features of the Cay Sal region contributes to the formation of meanders on the downstream end cannot be disregarded. Moreover, some internal readjustments of the structure of the stream could also be expected and reflected in

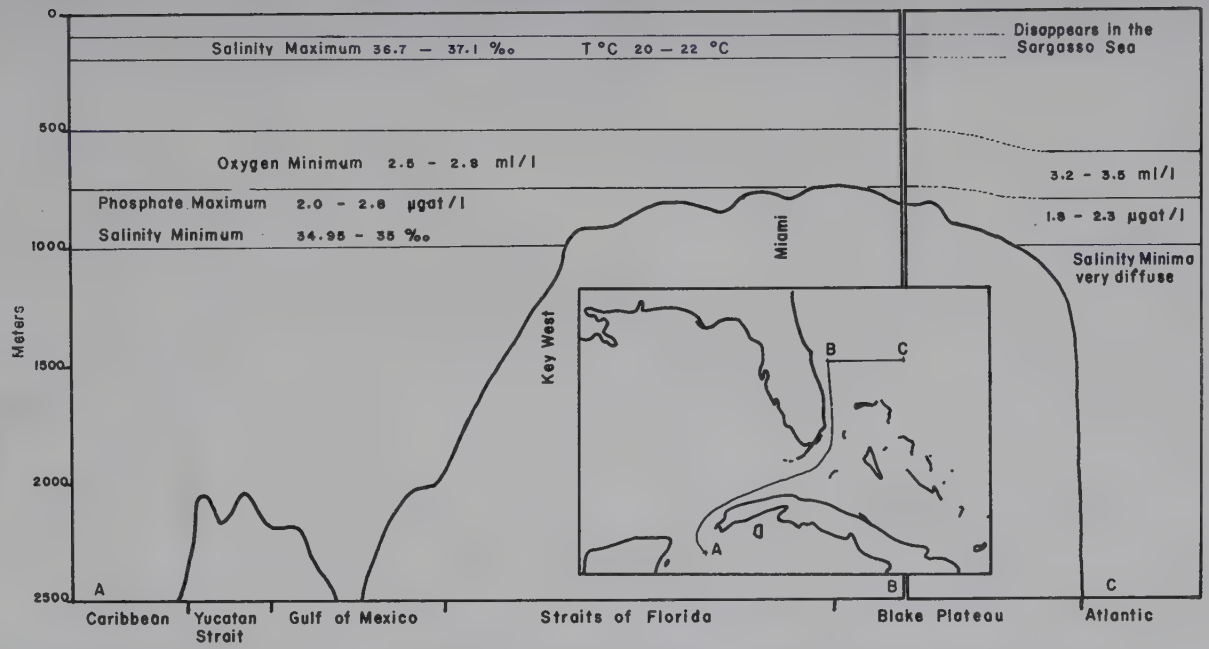

*FIGURE 18. Schematic distribution of water mass properties between the Caribbean and the Western Atlantic.

changes in the downstream water mass properties. More intensive sampling is planned in the Cay Sal region to study its influence upon the hydrography of the Northern Straits.

Conclusion

The results of the present work show that the Straits of Florida can be subdivided into several well-defined hydrographic regions.

1. The Eastern Gulf of Mexico and Southern Straits of Florida.

These two areas form an homogeneous hydrographic unit.

2. Cay Sal Region.

The Cay Sal Region is an area of hydrographic transition. The bathymetry of the western section strongly influences the flow of water at different depths The waters above 350 m can flow directly northward across the Florida Key Bank, but the water below 400 m must follow a more northeasterly route. Santaren and Nicholas Channel receive unknown amounts of Western Atlantic Water through the old Bahama Channel.

3. Northern Straits of Florida.

The hydrographic conditions in the Northern Straits are acquired in the Cay Sal Region. The influx of Western Atlantic Water along the Bahama Banks and its effect upon the hydrography of the right hand edge of the Florida Current needs further investigation.

This study shows the necessity for careful location of the sampling stations if the collected data are to be analyzed for seasonal fluctuations. The stations must be located outside the influence of boundary meanders between water masses.

Oxygen can be used successfully to trace water masses in the Straits of Florida, especially in the study of the influx of Western Atlantic Water. When used in conjunction with its corresponding temperature-salinity relationships, the oxygen might also be used to identify the Edge Water in the Southern Straits.

Phosphate cannot be used as a tracer at least at the present time since the scarcity and unreliability of the available data are a stumbling block.

A schematic presentation of the general oceanographic features of the area, as interpreted from the results of the present study, is shown in Fig. 19.

The attempt to synthesize old and new information pertaining to the distribution of water mass properties in the Straits of Florida and related waters has been partially achieved. The inadequacies of present

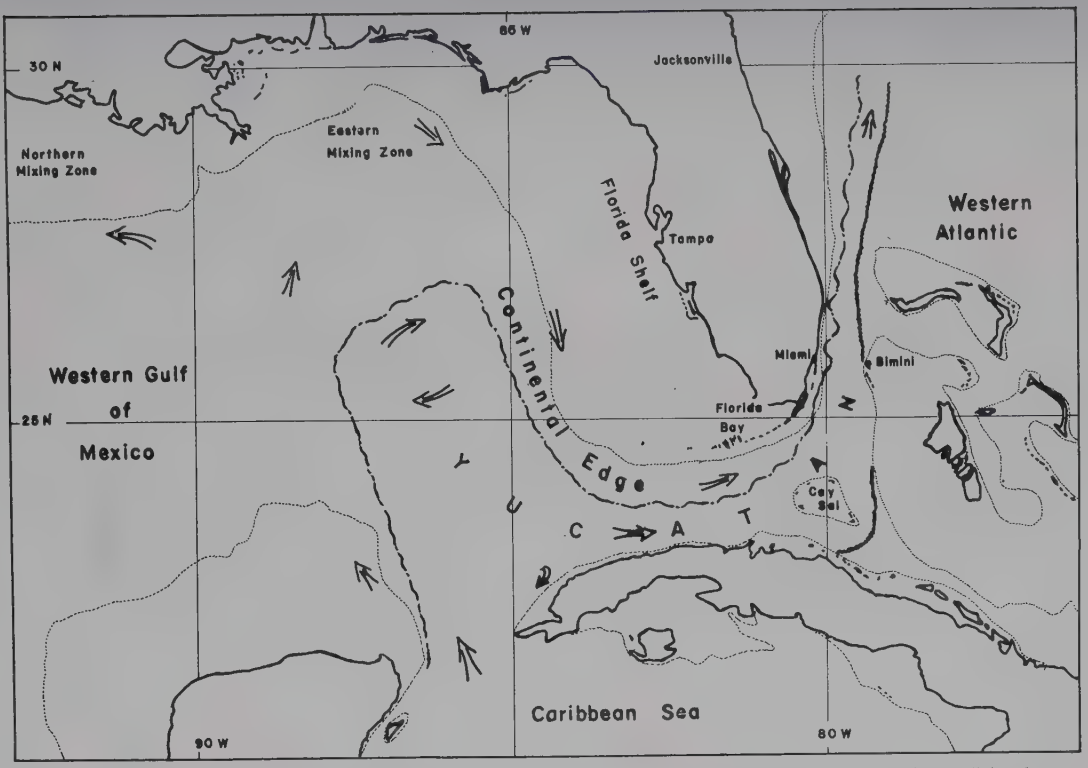

FIGURE 19. Boundaries of Water Masses of the Gulf of Mexico, Straits of Florida and Bahama Islands.

and past data and the lack of an homogeneous sampling program prevent adequate interpretation of the processes which influence and control the distribution of the properties studied.

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STUDIES ON HELMINTH PARASITES OF THE COAST OF FLORIDA I. DIGENETIC TREMATODES OF MARINE FISHES FROM TAMPA AND BOCA CIEGA BAYS WITH DESCRIPTIONS OF TWO NEW SPECIES. 1.[1]

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INTRODUCTION

The trematodes reported herein were collected from marine fishes captured by the authors, Dr. V. G. Springer, Messrs. K. Woodburn and D. J. Greeley of the Florida State Board of Conservation Marine Laboratory.

Further studies of the diseases and helminth parasites of marine fishes, birds, and mammals shall be published in connection with research currently being supported by the Florida State Board of Conservation.

Acknowledgments are extended to Dr. V. G. Springer for the identification of some fish hosts; to the U. S. Fish and Wildlife Service, Pass-a-Grille, Florida, through whose courtesy a camera-lucida was made available while this laboratory was obtaining said instrument; and to the Lerner Marine Laboratory of the American Museum of Natural History, Bimini, Bahamas, for support received while one of us (F.S.) collected trematodes which were used to give additional information of some species being compared in this paper.

Unless otherwise cited, all measurements are in millimeters.

SYSTEMATICS

Family BUCEPHALIDAE POCHE, 1907

1. *Bucephalus varicus* Manter, 1940

Host. *Caranx hippos* (Linn.): Common jack; family Carangidae
Incidence of Infection. In 1 of 1 host
Location. Mainly close to pyloric junction and a few scattered specimens along length of entire intestine
Locality. Bayboro Harbor, Tampa Bay, (new locality record) Florida
Discussion. Manter (1940) pictured variation of tentacles and displa-

[1]Contribution No. 18 from the Florida State Board of Conservation Marine Laboratory.

cement of organs in preserved *B. varicus* from the Tropical American Pacific and Tortugas, Florida. We have studied live *B. varicus* under slight coverslip pressure and can confirm the variations observed by Manter (1940).

B. varicus has been reported from no less than eleven different carangid species from Okinawa, the Red Sea, Tortugas, Florida, and the Tropical American Pacific. The only other record of *B. varicus* from *Caranx hippos* is by Bravo and Sogandares (1957) from the Pacific Coast of Mexico. This record is the first from *Caranx hippos* in the Atlantic Ocean and extends the northernmost distribution of *B. varicus* in the Gulf of Mexico.

Family Lepocreadiidae Nicoll, 1935

2. *Lepocreadium floridanus* n. sp.

(Figure 1)

Host. Lagodon rhomboides (Linn.); pinfish; family Sparidae

Incidence of Infection. In 4 of 4 hosts

Location. Pyloric ceca and anterior ¼ intestine

Locality. Bayboro Harbor, Tampa Bay, Florida

Diagnosis. (Based on 21 specimens): Body elongate, notched at posterior end, 0.754 to 1.092 long by 0.364 to 0.520 wide. Cuticle completely spined. Forebody 0.218 to 0.354 long. Posterior body 0.500 to 0.664 long. Oral sucker subterminal, 0.081 to 0.100 long by 0.091 to 0.100 wide. Acetabulum pre-equatorial, 0.091 to 0.100 long by 0.091 to 0.100 wide. Sucker ratio from 1:0.91 to 1.0. Prepharynx appearing to be absent to 1¼ longer than pharynx, depending upon contraction of forebody. Pharynx 0.045 to 0.054 long by 0.054 to 0.064 wide. Esophagus appearing to be absent or equal in length to pharynx, depending upon contraction of forebody. Ceca narrow, extending to near posterior end of body, ending blindly. Genital pore sinistral to midline of body, immediately preacetabular. Testes two, median and intercecal, post-equatorial, lobed, in series, in contact with each other; anterior testis usually about twice wider than long and less lobate than posterior testis, 0.063 to 0.109 long by 0.118 to 0.191 wide; posterior testis longer than wide, usually with a terminal posterior notch, 0.091 to 0.127 long by 0.118 to 0.191 wide. Cirrus sac extending posteriorly from genital pore to midway between acetabulum and ovary to almost in contact with ovary or anterior

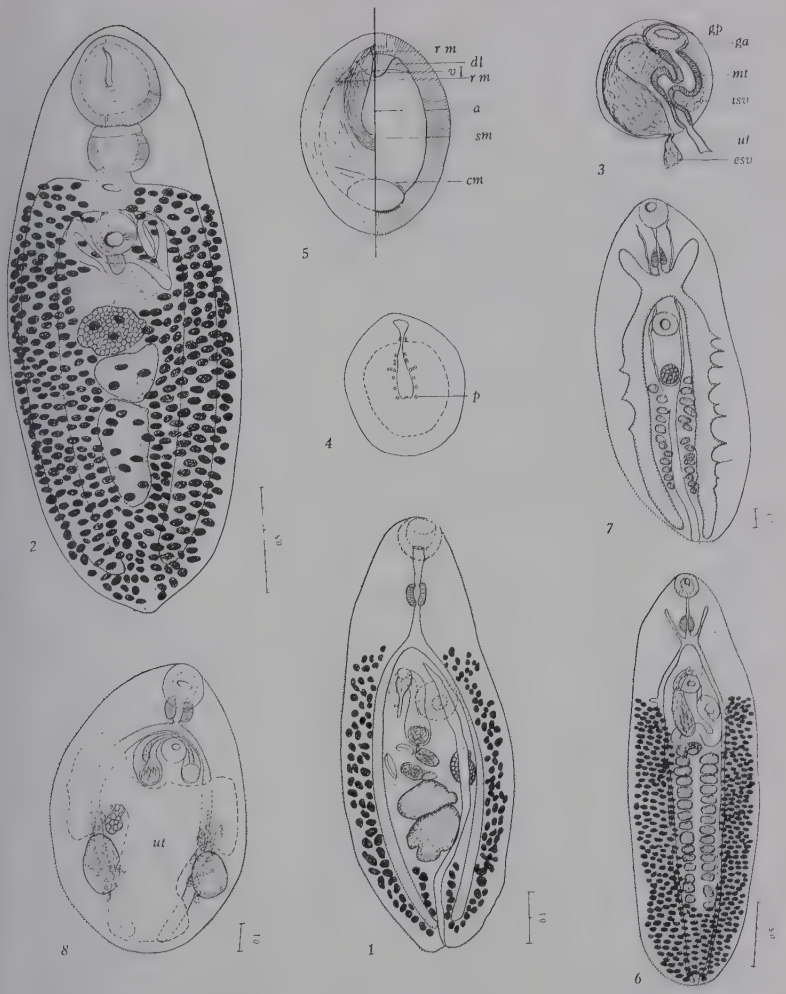

Fig. 1. *Lepocreadium floridanus;* dorsal view. Fig. 2. *Megasolena archosargi,* ventral view. Fig. 3. Same; freehand sketch of hermaphroditic sac; ventral view. Fig. 4. Same; freehand sketch of ventral surface of oral sucker showing arrangement of papillae. Fig. 5. Same; freehand sketch of oral sucker; optical section; left side showing arrangement of muscles on sucker surface and right side showing internal arrangement of lobes. Fig. 6. *Pleorchis americanus;* ventral view of mature specimen. Fig. 7. Same; ventral view of immature specimen. Fig. 8. *Diplomonorchis leiostomi;* ventral view; outline of area covered by uterus in dotted lines.

a, sucker aperture; cm, circular muscle; esv, external seminal vesicle; dl, dorsal lobe; ga, genital atrium; gp, genital pore; isv, internal seminal vesicle; mt, metraterm; p, papilla; rm, retractor muscle; ut, uterus; vl, ventral lobe (camera lucida drawings except where noted; projected scales in millimeters).

testis, depending upon contraction of posterior body; with muscular unspined cirrus in anterior 3/4 sac and internal seminal vesicle in distal ¼ sac. External seminal vesicle present, not surrounded by prostatic cells. Ovary usually with three lobes, sometimes with only one lobe, depending upon angle of observation; always dextral to median line of specimen and in contact with right cecum, anterior to or level with foretestis, 0.063 to 0.091 by 0.063 to 0.072 wide. Seminal receptacle clubshaped, median, immediately pretesticular. Vitellaria extending from level of pharynx or from level of crural junction, depending upon contraction of forebody, to posterior end of body; lateral to ceca, entering intercecal posttesticular space with one row of follicles on each side of excretory vesicle. Vitelline receptacle median, immediately pretesticular. Uterus short, entirely pretesticular, intercecal; entering muscular metraterm which is sinistral to cirrus sac and half as long. Excretory vesicle tubular, from between median posterior notch of body to level of crural junction; between testes and dextral cecum, partially overlapping ovary and acetabulum dorsally on its anterior course.

The name *floridanus* is to indicate the type locality, Florida.

Discussion. There are fifteen species known in the genus *Lepocreadium* Stossich, 1904. These species are as follows: *L. album* (Stossich, 1890) Stossich, 1904; *L. archosargi* Pearse, 1949; *L. bimarinum* Manter, 1940; *L. clavatum* (Ozaki, 1932) Yamaguti, 1938; *L. elongatum* (Nagaty, 1942) Manter, 1945; *L. incisum* Hanson, 1955; *L. micropogoni* Pearse, 1949; *L. ovale* Manter, 1931; *L. pegorchis* (Stossich, 1901) Stossich, 1904; *L. pyriforme* (Linton, 1899) Linton, 1940; *L. retrusum* Linton, 1940; *L. setiferoides* (Miller and Northup, 1926) Martin, 1938; *L.* sp. Szidat, 1950; *L. trulla* (Linton, 1907) Linton, 1910; and *L. trullaforme* Linton, 1940.

The genus *Lepocreadium* Stossich, 1904, is closely related with *Aephidogenes* Nicoll, 1915; *Allolepidapedon* Yamaguti, 1950; *Dermadena* Manter, 1945; *Lepidapedon* Stafford, 1904; *Lepocreadioides* Yamaguti, 1936; *Neolepidapedon* Manter, 1954; *Opechona* Looss, 1907 (Syns.: *Pharyngora* Lebour, 1908; *Prodistomum* Linton, 1910); *Opechonoides* Yamaguti, 1940; and *Pseudocreadium* Layman, 1930 (Syns.: *Hypocreadium* Ozaki, 1936, *Leptocreadium* Ozaki, 1936). In some instances there is a narrow gap separating these genera. These lepocreadiid genera are characterized by possessing a cirrus sac with an external seminal vesicle, suckers without papillae or projections, and unmodified forebodies (viz. *Bianium* Stunkard, 1931). The fol-

lowing key will serve to separate *Lepocreadium* from closely related genera.

KEY TO *LEPOCREADIUM* AND CLOSELY RELATED GENERA

1. External seminal vesicle entirely or partially surrounded by prostate gland cells 2
1¹. External seminal vesicle never surrounded by prostate gland cells 5
2. Metraterm and cirrus sac not opening into common genital atrium, instead opening separately to outside ..... *Aephidogenes*
2¹. Metraterm and cirrus sac opening into common genital atrium 3
3. Uroproct present ..... *Allolepidapedon*
3¹. Uroproct absent, instead ceca ending blindly 4
4. Prostate cells of external seminal vesicle without surrounding membrane ..... *Neolepidapedon*
4¹. Prostate cells of external seminal vesicle with surrounding membrane ..... *Lepidapedon*
5. Epithelial esophagus present, prostate gland cells partially surrounding cirrus sac ..... *Opechona*
5¹. Epithelial esophagus absent, prostate gland cells never surrounding cirrus sac 6
6. Testes side by side 7
6¹. Testes not side by side, either in series or oblique 8
7. Ventral surface of body with glandular projections which are sometimes seen with considerable difficulty in whole mounts ..... *Dermadena*
7¹. Ventral surface of body without glandular projections .... *Pseudocreadium*
8. Ceca ending at testes ..... *Opechonoides*
8¹. Ceca ending at posterior end of body 9
9. Genital pore in vicinity of acetabulum, usually dextral to midline of body and immediately preacetabular ..... *Lepocreadium*
9¹. Genital pore never in vicinity of acetabulum, usually dextral and lateral to oral sucker ..... *Lepocreadioides*

The anterior extent of the excretory vesicle has been described for the following species of *Lepocreadium*: *L. album; L. archosargi; L. bimarinum; L. clavatum; L. micropogoni;* and *L. setiferoides.* Manter (1940) was not sure of the anterior extent of the excretory vesicle of *L. bimarinum* and stated that it appeared to extend to the anterior testis. One of us, (F. S.), has one specimen of *L. bimarinum* collected from *Pimelotopon pulcher* (Ayres), type host, by W. R. Montgomery in La Jolla, California, and the excretory vesicle appears to terminate dorsal to the anterior testis as recorded by Manter (1940). In addition, a study of specimens identified as *L. trulla* from *Ocyurus chrysurus* (Bloch), *Lutjanus analis* (Cuv. & Val.) and *Lutjanus buccanella* (Cuv. & Val.), collected by one of us (F. S.) in Bimini, B.W.I., indicates that the excretory bladder never extends anterior to the posterior border of the ovary, usually only to the anterior testis.

The anterior extent of the excretory vesicle is not known for the

following species: *L. incisum; L. ovale; L. s*p. Szidat, 1950; *L. retrusum;* and *L. trullaforme.*

L. floridanus differs from *L. album; L. archosargi; L. micropogoni, L. ovale, L. trullaforme, L. bimarinum, L. pyriforme* and *L. setiferoides* by possessing a lobed as compared with unlobed ovary. *L. floridanus* further differs from *L. archosargi, L. micropogoni,* and *L. bimarinum* by possessing an excretory vesicle which extends to the crural junction as compared with excretory vesicle never extending anterior to ovary; from *L. ovale* by possessing testes in contact and in series, and vitellaria extending to crural junction in extended specimens as compared with testes oblique and vitellaria extending to midpharynx in an apparently extended specimen; from *L. trullaforme* by possessing testes in series and in contact, and narrower body, as compared with testes oblique, not in contact and a much wider body; from *L. pyriforme,* from *Palinurichthys perciformis,* by lacking a spiny cirrus, and ovary dextral to midline (a constant character in all 21 of our specimens), as compared with cirrus spined and ovary median; from *L. setiferoides* by possessing an excretory vesicle which extends anterior to acetabulum and testes in contact and in series as compared with excretory vesicle which extends to acetabulum and testes oblique and not in contact.

In connection with species of *Lepocreadium* with unlobed ovaries, *L. archosargi* and *L. micropogoni* are probably synonyms of *L. ovale.* A restudy of the type specimens of all three species would be necessary in order to confirm this point. Linton (1940) apparently has a heterogeneous assemblage of species listed under *Lepocreadium pyriforme.* Linton's (1940; Figure 48) shows prostate cells surrounding the posterior end of the cirrus sac and it may well be that he has confused a species of *Opechona* with *Lepocreadium.* Linton (1940) does not mention the presence of an epithelial esophagus. Here again a study of Linton's material is necessary.

L. floridanus resembles *L. clavatum, L. elongatum, L. incisum* and *L. trulla* by possessing a lobed ovary. *L. floridanus* differs from *L. clavatum* and *L. trulla* by possessing an excretory vesicle which extends anteriorly to the level of the crural junction as compared with excretory vesicle never extending anterior to acetabulum (*L. clavatum*) or to anterior testis or ovary (*L. trulla*); from *L. incisum* by lacking an external seminal vesicle which extends to posterior testis; from *L. elongatum* by possessing testes in series as compared to testes

oblique; from *L. retrusum* by possessing vitellaria which extend anteriorly past acetabulum as compared with vitellaria never extending to acetabulum.

Family ACANTHOCOLPIDAE Lühe, 1909

3. *Pleorchis americanus* Lühe, 1906

Host. Cynoscion nebulosus (Cuv. & Val.); spotted squeteague; family Sciaenidae

Incidence of Infection. In 1 of 1 host

Location. Intestine, close to pyloric cecae

Locality. Bayboro Harbor, Tampa Bay, Florida; new locality record

Discussion. The presence of *P. americanus* in Tampa Bay establishes a new locality record and extends the southern range of the species. Sparks (1958) has reported *P. americanus* from Grand Isle, Louisiana.

P. americanus was formerly known from *Cynoscion* spp. in Woods Hole, Massachusetts, and from Beaufort, North Carolina, under the name of *Distomum polyorchis* and *Pleorchis polyorchis.* Lühe (1906) recognized specific differences between Linton's (1901) misidentified taxon, "*Distomum polyorchis* Stoss." from *Cynoscion regalis* in Woods Hole, Massachusetts, and named *P. americanus* for this species of Linton. Manter (1931) unaware of Lühe's new name for Linton's "*Distomum polyorchis* Stoss.", identified the American Atlantic *Pleorchis* as "*Pleorchis polyorchis* (Stoss.)." Manter (1949) later clarified the nomenclature and status of the taxon misidentified by both Linton (1901) and Manter (1931). In addition, Manter (1949) pointed out that *Pleorchis lintoni* Yamaguti, 1938, a name given to Linton's (1901) "*Distomum polyorchis* Stoss." through unawareness of Lühe (1906), was a synonym of *P. americanus.* Yamaguti (1942) transferred *Pleorchis oligorchis* Johnston, 1913 to the genus *Schistorchis* Lühe, 1906. In connection with the genus *Schistorchis,* we would like to point out that the genus *Megacreadium* Nagaty, 1956 is a synonym of *Schistorchis* Lühe 1906. The species *Megacreadium tetraodontis* Nagaty, 1956 becomes *Schistorchis tetraodontis* (Nagaty, 1956) n. comb. Both *Schistorchis carneus* Lühe, 1906 and *S. tetraodontis* are found in the fish genus *Tetraodon* from the same general area of the world. The presence of eight testes separates *S. tetraodontis* from other species of *Schistorchis.*

Family HAPLOPORIDAE Nicoll, 1914

4. *Megasolena archosargi* n. sp.

(Figures 2 to 5)

Host. Archosargus probatocephalus (Walbaum); sheepshead; famil Sparidae

Incidence of Infection. In 3 of 3 hosts

Location. Mid-intestine

Locality. Bayboro Harbor, Tampa Bay, Florida

Diagnosis. (Based on one sectioned specimen and five whole mounts. Body robust, elongate, flattened, broadest at middle; 2.21 to 2.7 long by 0.99 to 1.14 wide. Forebody from 0.70 to 0.89 long Posterior body from 1.30 to 1.69 long. Cuticle of anterior 1/3 bod heavily spined; spines decreasing in size towards posterior end of bod to increase slightly in size close to posterior end of body. Darkl pigmented flakes which may represent "eyespots" lateral to posterio edge of oral sucker and pharynx. Oral sucker subterminal, 0.36 t 0.42 long by 0.33 to 0.46 wide; with one ventral and dorsal media internal lobe at anterior end (Fig. 5); with papillae surrounding suck er aperture (Fig. 4); with sucker aperture controlled by special super ficial musculature (Fig. 5). Acetabulum approximately in anterio 1/3 body; 0.17 to 0.21 long by 0.18 to 0.23 wide. Sucker ratio fron 1: 0.55 to 0.79. Prepharynx lacking muscular ring, approximatel ½ to 7/8 length of pharynx. Pharynx with anterior band of circula muscles, pyriform in shape; 0.18 to 0.23 long by 0.25 to 0.33 wide Esophagus approximately ½ length of pharynx. Ceca voluminous extending to near posterior end of body, ending blindly. Genital por median between pharynx and acetabulum. Testes two, interceca postequatorial, in series and in contact with each other; anterior testi 0.21 to 0.34 long by 0.26 to 0.36 wide; posterior testis usually abou twice length of anterior testis, 0.39 to 0.51 long by 0.26 to 0.36 wide Hermaphroditic sac extending dorsally from genital pore, in contac with or slightly overlapping anterior border of acetabulum. Interna seminal vesicle connecting with metraterm proximal to genital atriun (Fig. 3); surrounded by prostate cells. External seminal vesicle ex tending from posterior tip of hermaphroditic sac dorsal to acetabulum to between acetabulum and ovary or almost in contact with ovary Ovary slightly lobed, median and usually in contact with anterio testis, 0.21 to 0.23 long by 0.26 to 0.33 wide. Mehlis' gland large

ccupying most of the intercecal space between half distance from vary to acetabulum. Laurer's canal not observed. Vitellaria completely surrounding body, laterally, dorsally and ventrally from level f hermaphroditic sac to posterior end of body. Uterus preovarian, ntercecal, entering muscular metraterm in hermaphroditic sac on nistral side. Eggs 73.5 to 88.2 microns long by 42 to 48.3 microns ide. Excretory vesicle Y-shaped, bifurcating at posterior edge of vary, with branches extending dorsally and laterally to level of midcetabulum. Lymphatic vessels present but exact number and arrangement are not clearly visible.

The name *archosargi* is for the host *Archosargus probatocephalus*. *iscussion. Megasolena archosargi* is closely related to *Megasolena strix* Linton, 1910 from which it differs by lacking a prepharyngeal nuscular ring. The absence of this prepharyngeal muscular ring would erhaps be considered a generic character. One of us (F. S.) has pecimens of a new species of *Megasolena* from the Gulf of Panama, hich possesses a much reduced muscular collar. The status of the pecies of *Megasolena* shall be more fully discussed when a manuscript ne of us, (F. S.), has prepared on trematodes of marine fishes of the Gulf of Panama and Bimini, B.W.I., is published.

Manter (1957) has presented a strong argument to show that the Haploporidae Nicoll, 1914, Waretrematidae Srivastava, 1939, and Megasolenidae Skrjabin, 1942 are synonyms. All three families possess a hermaphroditic sac and reduced, follicular or more or less ubular vitellaria. There appears to be close intergradation of genera n these families. Until such time as life-cycle studies indicate the pposite, we shall retain Manter's (1957) views regarding the families Waretrematidae and Megasolenidae as synonyms of the Haploporidae.

In connection with Manter's (1957) Table III (p. 191), we would ke to point out that the presence or absence of eggs, *en utero,* conaining oculate miracidia is dependent upon the maturity of the egg n some species and should be used with caution. Szidat (1954) ndicates that only the mature eggs of *Saccocoeloides elongatus* Szidat, 954 possess miracidia with eyespots. In addition, *Dicrogaster contractus* Looss, 1902, *Haploporus lateralis* Looss, 1902, *Megacoelium lecostomi* Szidat, 1954, and perhaps one other species of haploporid *ensu* Nicoll, 1914 are described as possessing eggs lacking oculate niracidia.

The Haploporidae *sensu* Nicoll, 1914 may have connections with ne Monorchiidae. It would not be difficult to visualize that a mem-

brane surrounding an unspined male and female genitalia of a monorchiid would produce a haploporid. In addition, most haploporids *sensu* Nicoll, 1914 and monorchiids share the following characters, one testis, reduced vitellaria, spined cuticle, ceca which frequently terminate in the vicinity of the testis, and uterus extending behind testis. The uterus of the Megasolenidae is usually preovarian.

Family MONORCHIIDAE Odhner, 1911

5. *Diplomonorchis leiostomi* Hopkins, 1941

(Figure 8)

Hosts. Bairdiella chrysurus (Lacépède); silver perch; new host record; family Sciaenidae; and *Lagodon rhomboides* (Linn.); pinfish; new host record; family Sparidae

Incidence of Infection. In 1 of 1 *B. chrysurus* and 1 of 4 *L. rhomboides*

Location. Intestine, exact location not noted

Locality. B. chrysurus from Cabbage Key, Boca Ciega Bay, and *L. rhomboides* from Bayboro Harbor, Tampa Bay, Florida; new locality record

Discussion. D. leiostomi has been previously reported from *Leiostomus xanthurus* and sometimes *Orthopristis chrystopterus,* in Beaufort, North Carolina, by Hopkins (1914). This record extends the southern range of *D. leiostomi* and establishes two new host records. Sparks (1958) has reported *D. leiostomi* from Grand Isle, Louisiana.

Family FELLODISTOMATIDAE Nicoll, 1913

6. *Steringotrema corpulentum* (Linton, 1905) Manter, 1931

(Figure 9)

Host. Lagodon rhomboides (Linn.); pinfish; family Sparidae

Incidence of Infection. In 1 of 4 hosts

Location. Intestine proximal to pyloric ceca

Locality. Bayboro Harbor, Tampa Bay, Florida; new locality record

Discussion. Linton (1905) originally described *S. corpulentum* from pinfishes in Beaufort, North Carolina. Manter (1931) listed, added a correction to Linton's description, and pictured, but did not redescribe *S. corpulentum.* To our knowledge, *S. corpulentum* has not been reported from any area other than Beaufort, North Carolina.

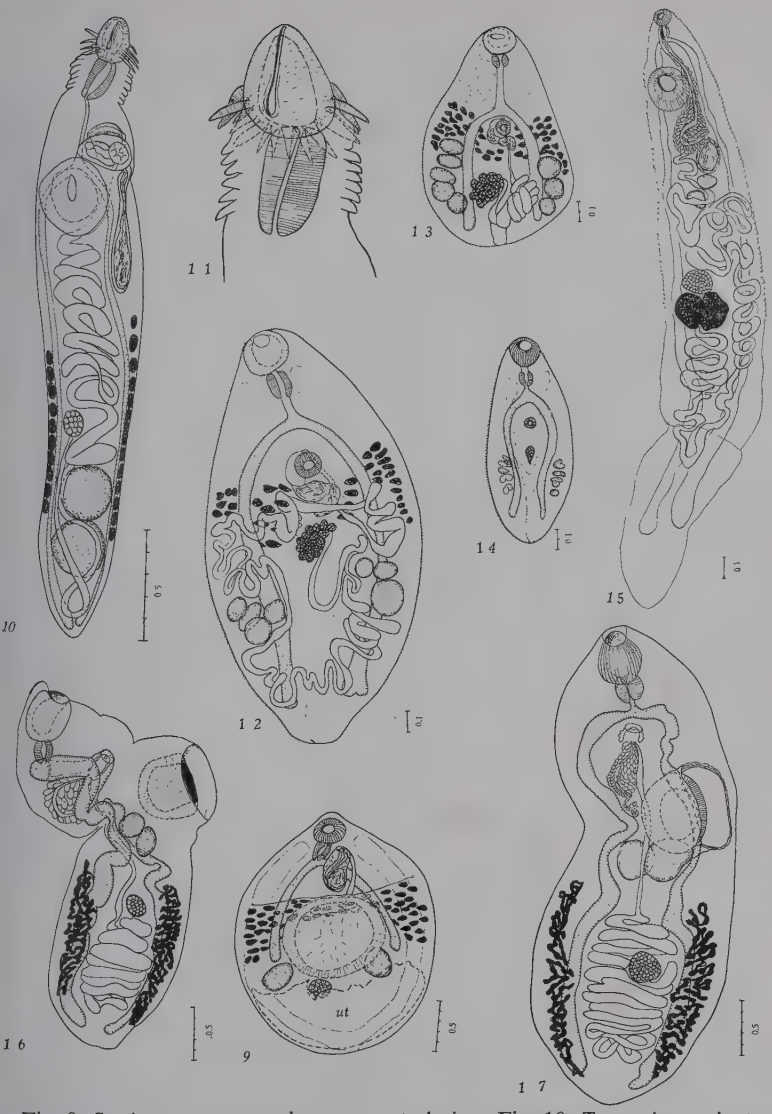

Fig. 9. *Steringotrema corpulentum;* ventral view. Fig. 10. *Tergestia pectinata,* ventral view of entire specimen. Fig. 11. Same; camera lucida drawing of anterior end of body with sucker tentacles sketched in. Fig. 12. *Siphodera vinaledwardsi;* ventral view of mature, normally extended specimen. Fig. 13. Same; showing variation due to contraction; ventral view of mature specimen with extended forebody and contracted hindbody. Fig. 14. Same; ventral view of immature specimen. Fig. 15. *Parahemiurus merus;* ventral view. Fig. 16. *Sclerodistomum sphoeroides;* twisted specimen with forebody in lateral view and posterior body in ventral view. Fig. 17. Same; ventral view.

a, sucker aperture; cm, circular muscle; esv, external seminal vesicle; dl, dorsal lobe; ga, genital atrium; gp, genital pore; isv, internal seminal vesicle; mt, metraterm; p. papilla; rm, retractor muscle; ut, uterus; vl, ventral lobe (camera lucida drawings except where noted; projected scales in millimeters).

The genital pore in well extended specimens of *S. corpulentum* is located at cecal bifurcation as pictured by Manter (1931). When the forebody is much contracted, the genital pore may vary in position, sometimes appearing to be proximal to the posterior border of oral sucker.

7. *Tergestia pectinata* (Linton, 1905) Manter, 1940

(Figures 10 to 11)

Host. Caranx crysos (Mitchell); hard-tailed jack; new host record; family Carangidae

Incidence of Infection. In 1 of 1 host

Location. Intestine, exact location not observed

Locality. Bayboro Harbor, Tampa Bay (new locality record), Florida

Discussion. T. pectinata was distinguished from *T. laticollis* (Rud. 1819) Odhner, 1911 on the basis of sucker ratio 1:2 as compared with 1:1 in *T. laticollis* by Manter (1947). Manter (1947) mentions the sinuosity of the seminal vesicle of *T. pectinata* as an additional distinguishing character. The specimen figured here (Fig. 10) differs by possessing a seminal vesicle which is so swollen with sperm that no convolutions are apparent.

T. pectinata is previously known from Woods Hole, Massachusetts, Beaufort, North Carolina (type locality), and Tortugas, Florida. The occurrence of *T. pectinata* in *Caranx crysos* from Tampa Bay is the northernmost distribution in the Gulf of Mexico and a new host record.

Family Cryptogonimidae Ciurea, 1933

8. *Siphodera vinaledwardsi* (Linton, 1901) Linton, 1910

(Figures 12 to 14)

Host. Opsanus beta (Goode and Bean); toadfish; new host record; family Batrachoidiidae

Incidence of Infection. In 6 of 8 hosts

Location. Anterior ¼ intestine

Locality. Mullet Key, Boca Ciega Bay (new locality record), Florida

Discussion. S. vinaledwardsi has been reported from the following localities: Woods Hole, Massachusetts, by Linton (1901), Manter (1926), and Cable and Hunnienen (1942); from Bermuda by Linton (1908) and Hanson (1950); from Beaufort, North Carolina, by Linton (1905) and Manter (1931); from Tortugas, Florida, by Linton

(1910) and Manter (1947). Cable (1956) reported a cercaria from Puerto Rico which "... is so similar to the cercaria of *Siphodera vinaledwardsi* that it seems certain to be the larva of what may be the same trematode found in fishes seined in shallow water." The present record is the northernmost in the Gulf of Mexico.

Figure 12 shows a specimen of *S. vinaledwardsi* in which the forebody is extended and the hindbody somewhat contracted. Variation in the number of testes was also encountered. The normal number of testes is apparently four on each side of the body. Sometimes a specimen may have three testes on one side and from four to five on the other side of the body.

The present indications are that *S. vinaledwardsi* possesses little host specificity, being known from no less than five host species of the families Batrachoidiidae, Lutjanidae, and Pomadasyidae, mainly carnivorous fishes.

Family Hemiuridae Lühe, 1901

9. *Parahemiurus merus* (Linton, 1910) Woolcock, 1935

(Figure 15)

Hosts. Harengula pensacolae (Goode and Bean); new host record; family Clupeidae; *Urophycis floridanus* Dean and Dresel; new host record, family Gadidae

Incidence of Infection. In 2 of 2 *H. pensacolae* and in 1 of 2 *U. floridanus.*

Location. Stomach of all hosts

Locality. H. pensacolae from Bayboro Harbor, Tampa Bay (new locality record), and *U. floridanus* from Bird Key, Boca Ciega Bay (new locality record), Florida

Discussion. U. floridanus enters the shallow coastal waters of Western Florida during the winter months, possibly acquiring *P. merus* here. *H. pensacolae* is apparently a year around resident of the coast of Florida.

P. merus grew to a longer size in *H. pensacolae* than in *U. floridanus* although intermediate conditions occur in our material. The egg sizes of *P. merus* from *H. pensacolae* and *U. floridanus* agree and appear to be constant regardless of the size of the worm specimen.

P. merus is known from at least 6 completely unrelated host families and is perhaps originally a parasite of the Clupeoidei. Collection records by Manter (1940, 1947), by Sparks (1958) and by one of

us (F. S.) in Bimini, B.W.I., indicates *P. merus* only very rarely in fishes other than Clupeoidei from the Pacific and Atlantic Waters of this Continent.

Any record of *P. merus* from *"Harengula macropthalma"* (vide Manter, 1947) should be taken with caution as this fish species has been the subject of an extensive revision by Rivas (1950).

10. *Sclerodistomum sphoeroides* Manter, 1947

(Figures 16 to 17)

Host. *Chilomycterus schoepfi* (Walbaum); spiny boxfish; new host record; family Diodontidae

Incidence of Infection. In 3 of 3 hosts examined

Location. Stomach

Locality. Cabbage Key, and Bird Key, Boca Ciega Bay (new locality record), Florida

Discussion. Manter (1947) named *S. sphoeroides*, a trematode, from the body cavity of a puffer, *Sphoeroides spengleri* (Bloch). We believe that Manter (1947) must have confused the inflated stomach of the puffer with the body cavity. When the stomach of puffers is inflated with air or water, the resultant cavity appears to be the coelom. If the intestine is traced forward, the connection with the, then almost membranous, stomach may be easily observed. In connection with other species of *Sclerodistomum, S. italicum* (Stossich, 1893) is known from the stomach of its host *Lichia amia*. The record of *S. diodontis* from the body cavity of *Diodon holocanthus* in the Mexican Pacific by Bravo (1954) is also probably in error. The location of *Sclerodistomum* spp. in the stomach of their respective hosts adds further evidence of their hemiurid habits.

Summary

1. The following trematodes, all new locality records for the Tampa Bay-Boca Ciega Bay area, are reported herein: *Bucephalus varicus* Manter, 1940 (Family Bucephalidae); *Lepocreadium floridanus* (this paper) (Family Lepocreadiidae); *Pleorchis americanus* Lühe, 1906 (Family Acanthocolpidae); *Megasolena archosargi* (this paper) (Family Haploporidae); *Diplomonorchis leiostomi* Hopkins, 1941 (Family Monorchiidae); *Steringotrema corpulentum* (Linton, 1905) Manter, 1931 and *Tergestia pectinata* (Linton, 1905) Manter, 1940 (Family Fellodistomatidae); *Siphodera vinaledwardsi* (Linton,

1901) Linton, 1910 (Family Cryptogonimidae); *Parahemiurus merus* (Linton, 1910) Woolcock, 1935 and *Sclerodistomum sphoeroides* Manter, 1947 (Family Hemiuridae).

2. New locality records for Florida are as follows: *Pleorchis americanus* Lühe, 1906, previously known from Woods Hole, Massachusetts, to Beaufort, North Carolina, and Grand Isle, Louisiana; *Diplomonorchis leiostomi* Hopkins, 1941, previously known from Beaufort, North Carolina and Grand Isle, Louisiana; and *Steringotrema corpulentum* (Linton, 1905) Manter, 1931, previously known only from Beaufort, North Carolina.

3. New species described are as follows: *Lepocreadium floridanus* and *Megasolena archosargi*.

4. New host records are as follows: *Diplomonorchis leiostomi* Hopkins, 1941 in *Bairdiella chrysurus* (Lacépède) and *Lagodon rhomboides* (Linn.); *Tergestia pectinata* (Linton, 1905) Manter, 1940 in *Caranx crysos* (Mitchill); *Siphodera vinaledwardsi* (Linton, 1901) Linton, 1910 in *Opsanus beta* (Goode and Bean); *Parahemiurus merus* (Linton, 1910) Woolcock, 1935 in *Harengula pensacolae* (Goode and Bean) and *Urophycis floridanus* Bean and Dresel; and *Sclerodistomum sphoeroides* Manter, 1947 in *Chilomycterus schoepfi* (Walbum).

5. The genus *Megacreadium* Nagaty, 1956 is considered a synonym of *Schistorchis* Lühe, 1906 and *Megacreadium tetraodontis* Nagaty, 1956 becomes *Schistorchis tetraodontis* (Nagaty, 1956) n. comb.

6. A key to *Lepocreadium* and related genera is presented.

Additional information concerning the anterior extent of the excretory vesicle of *Lepocreadium bimarinum* Manter, 1947, and *L. trulla* (Linton, 1907) Linton, 1910 is given.

7. Notes on the exact location of the trematodes within the fish digestive tract have been indicated whenever possible.

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THE VERTICAL DISTRIBUTION OF SOME INSHORE COPEPODS IN RELATION TO EXPERIMENTALLY PRODUCED CONDITIONS OF LIGHT AND TEMPERATURE[1]

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ABSTRACT

An experimental tower was used to test the effects of different gradients of light and temperature on the vertical distribution of three species of planktonic, inshore copepods. The three species used in the experimental tests were *Acartia tonsa* Dana, 1849, *Paracalanus parvus* (Claus, 1863), and *Calanopia americana* Dahl, 1894. Data indicated an optimum temperature range, outside of which there is a correlation between the occurrence of copepod concentrations and illumination values. Within the median temperature range there is little correlation of concentration with illumination.

INTRODUCTION

Field and experimental studies of the vertical distribution of zooplankton, particularly crustaceans, have demonstrated a relationship between illumination and diurnal movements (Cushing, 1951). Temperature also influences vertical distribution (Cushing, *op. cit.;* Moore *et al.,* 1953). Hardy and Bainbridge (1954) found that pressure equivalent to that at 20 meters depth caused certain larval decapods to swim upwards, but in general pressure has received scant attention as a factor affecting diurnal migration. Statistical analysis of oceanic plankton samples taken at various depths led to the development of a concept that vertical movements are regulated by responses to all three factors (Moore and Corwin, 1956). In 1956, The University of Miami Marine Laboratory received a grant from the National Science Foundation to test this concept experimentally.

Although the primary purpose of the project is to test the reactions of oceanic species to different gradients of light and temperature at various pressures, plankton from Biscayne Bay, just outside the laboratory, was used in preliminary tests of the apparatus. This plankton was readily obtained and could be used within minutes of capture. The results of these tests, in which animals were exposed to gradients of light and temperature but not to pressure, were presented by the author in a master's thesis (1958) at the University of Miami and are

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reported here together with the results of several additional experiments run after the thesis was completed.

The experimental apparatus was designed by H. B. Moore and H. B. Owre with the assistance of Robert W. Thornhill, whose skill in design and construction greatly facilitated test procedures. Credit should be given to Drs. Owre and Moore for their assistance and advice. Dr. Thomas Bowman of the Division of Marine Invertebrates, U. S. National Museum, also assisted the work by his identification of one of the test animals.

Apparatus

A plastic insert, described later, fits into a stainless steel tube, 10 feet 6 inches long, 11 inches in outside diameter and 10 inches in inside diameter which extends down from the second floor of the building, through the floor, to the ground. The sealed base of the tube rests in a fifty-gallon oil drum used to hold ice for cooling the water in the tube. A flange, designed to receive a pressure lid, is welded around the top of the tube and directly over the tube, attached to the ceiling of the second story of the building, is a block and tackle used to raise and lower the plastic insert by means of a hand winch bolted to the floor.

The insert, constructed of hard, clear plastic with stainless steel fittings, consists of ten linearly arranged chambers, each measuring 7x7 x11 inches. There are "O"-ring seals between the chambers which form a water-tight joint. The entire structure is held together by four stainless steel tie rods which pass through plastic supports on the outside of each chamber. At the base of each compartment is a set of three movable louvers which are left open during an experiment, allowing the animals free movement. All sets of louvers can be closed simultaneously by activating a closing mechanism by means of a solenoid switch. A one-inch plug forms a removable port in one side of each chamber. In every second chamber the plug receives a plastic tube from the surface. These tubes allow circulation of water within the insert. Another series of plastic tubes, designed to circulate the water in the space between the insert and the steel tube, extend along the outside of the structure and vent at the even-numbered chambers. This combination of tubes makes it possible to circulate water inside the insert, outside it, or from one to the other. The aperture of the tubes which vent on the inside of the apparatus is small enough to prevent any appreciable number of planktonic organisms from enter-

ing them during an experiment. A one-half inch "Jabsco" pump is used to circulate the water and to remove the contents of each chamber at the end of a test. Into each chamber is inserted a thermister with a lead to a microamp meter. The thermisters are calibrated to read from 0-50°C with an error of ± 1°C.

Prior to a test a temperature gradient was established in the water-filled tube. Low temperatures were obtained by packing the 50-gallon drum mentioned earlier with ice, higher temperatures by heating the water in the top of the tube with a 500 ohm immersion heater. The water circulation system allowed adjustment of the gradient.

Illumination was supplied by light bulbs from 25-2500 watts used with a photographic reflector. One test was run with sunlight reflected down the steel tube by mirrors but this method was not developed to satisfaction. A waterproofed solar battery, attached to a plug which fits in any of the chamber ports and connects to a microamp meter, was used to measure the illumination, given by each light bulb, in each chamber. The illumination gradient showed a 500 fold difference between top and bottom chamber readings.

Water for the experiments was drawn from the Bear Cut channel which connects Biscayne Bay to the ocean, run into a settling tank on the roof of the building, then through a glass wool filter into a 50-gallon oil drum, used as a second settling tank, and then into the experimental tube. The clarity of the water in the channel varied but through the use of the two settling tanks and the glass wool filter a fairly constant clarity was maintained.

Experimental Animals

Animals were obtained by trailing a three-fourths meter plankton net of the Discovery type (Kemp, Hardy and Mackintosh, 1929) from the laboratory dock, where the water is about nine feet deep, for periods varying from ten to thirty minutes. It was found that a towing time of more than thirty minutes tended to damage the plankton and when necessary a series of tows was made instead of one long tow.

Three inshore copepod species were found to occur in sufficient numbers for study, *Acartia tonsa* Dana, 1849, *Calanopia americana* Dahl, 1894, and *Paracalanus parvus* (Claus, 1863). There are two species of *Acartia* in the area, *tonsa* and *spinata, A. tonsa* being the more abundant. Because of the morphological similarity between *A. tonsa* and *A. spinata,* the number of copepods identified from each

test, and the time which would have been required for definite identification, the two species have been combined under *A. tonsa.*

Procedure

Just before each experiment, while the temperature gradient was being adjusted, tows were made until enough plankton was accumulated; the catches were kept in a cool, dark place to prevent damage from light or abrupt temperature change. Usually within 30 minutes after capture, the unsorted plankton was injected into the chamber where the temperature most closely approximated that of the water from which it was captured. A plastic lid was placed over the top of the insert and water was added until the level was one inch above the lid. The light source was suspended over the mouth of the tube, one foot above the lid of the insert, and the test begun.

The duration of the experiments was determined by roughly computing the time required for the slowest moving copepod, *Paracalanus parvus,* to sink or swim from one end of the tube to the other or for a dead or damaged copepod to sink to the bottom chamber. This amounts to fifteen or twenty minutes, although all tests were run for thirty minutes.

At the end of a test the louvers were closed, the temperature in each chamber was again read and this reading used in the study of the data. It was found that temperature variation in the chambers during an experiment was not more than $\pm$ 7°C. A line voltage meter was used during some of the tests to measure voltage fluctuations in the lines but variation was insignificant.

In order to remove the contents of the apparatus the excess water covering the lid was pumped out, the lid removed, and the winch line attached to the top of the insert. As the insert was raised to permit drainage of chamber one, two, three, etc., the water levels in the insert and the tube were kept equal by adding water to the tube. Using the pump noted earlier, the contents of each chamber were pulled through a Buchner funnel fitted with a filter of number 20 plankton netting. The animals thus removed from each chamber were then washed into a solution of formalin.

In identifying and counting the copepods, total counts were made unless the animals were extremely numerous, in which case a 10 or 20 per cent subsample was used. Because of the time limitation, only adults were counted.

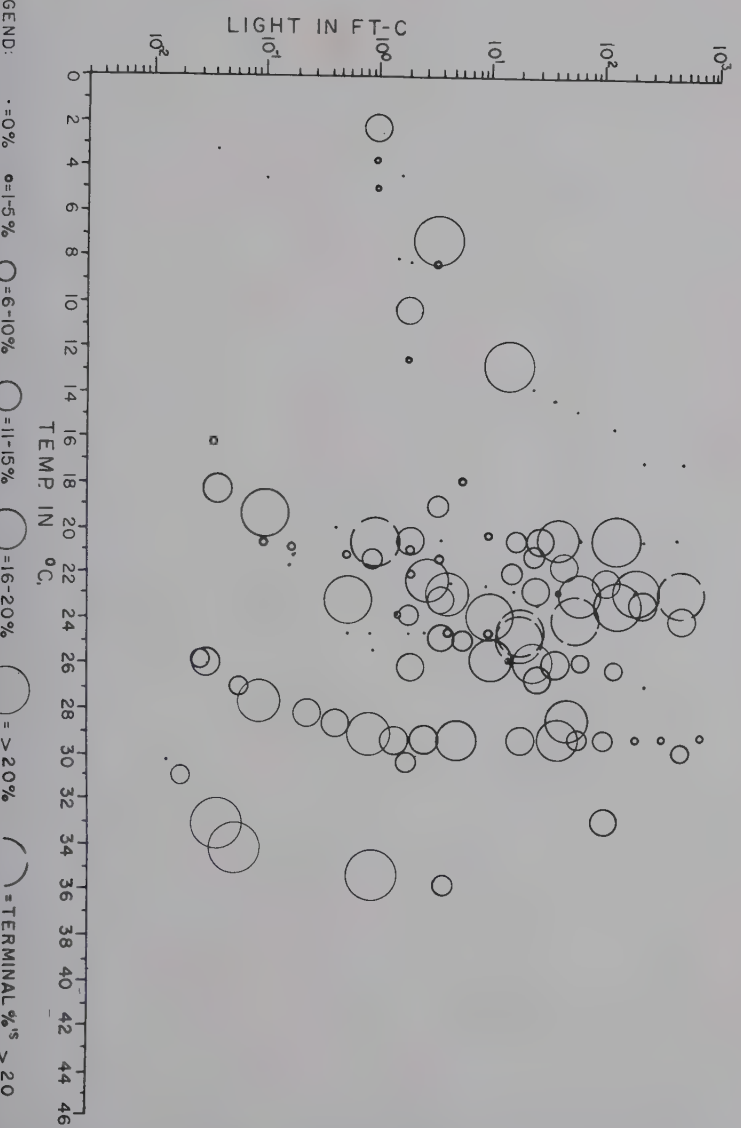

FIG. 1 Distribution of *Calanopia americana* Dahl, 1894 in the experimental apparatus. The size of the circle indicates the per cent of the total count of an experiment which occurs at the various values of light and temperature.

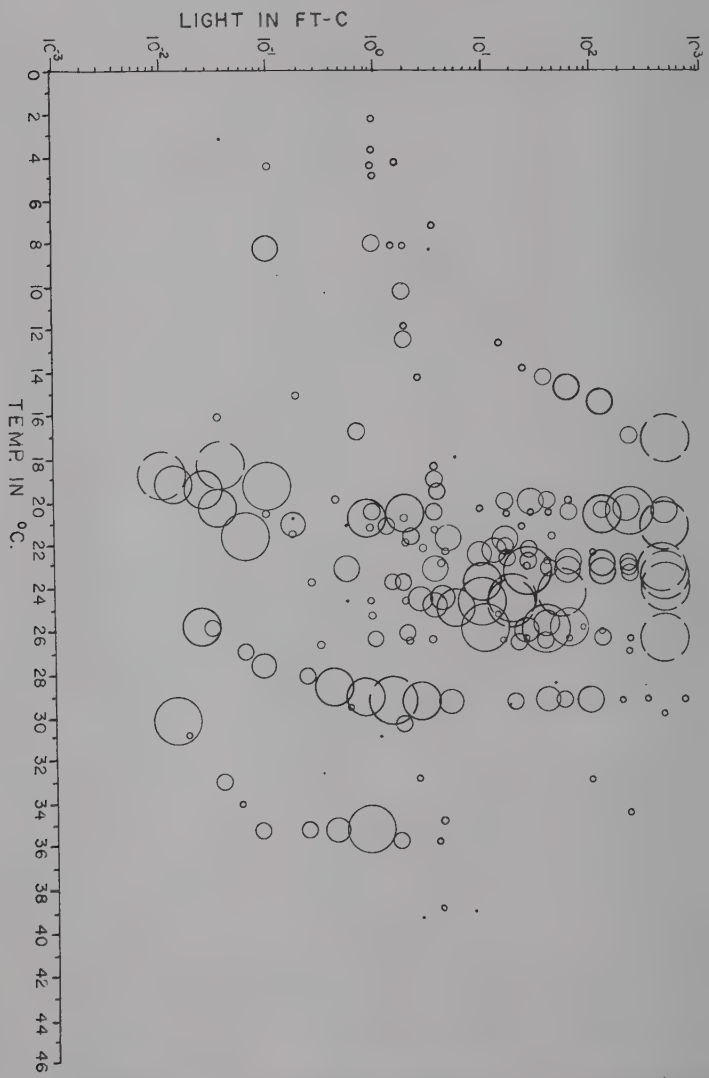

FIG. 2. Distribution of *Paracalanus parvus* (Claus, 1863) in the experimental apparatus. For explanation of the symbols used see Fig. 1.

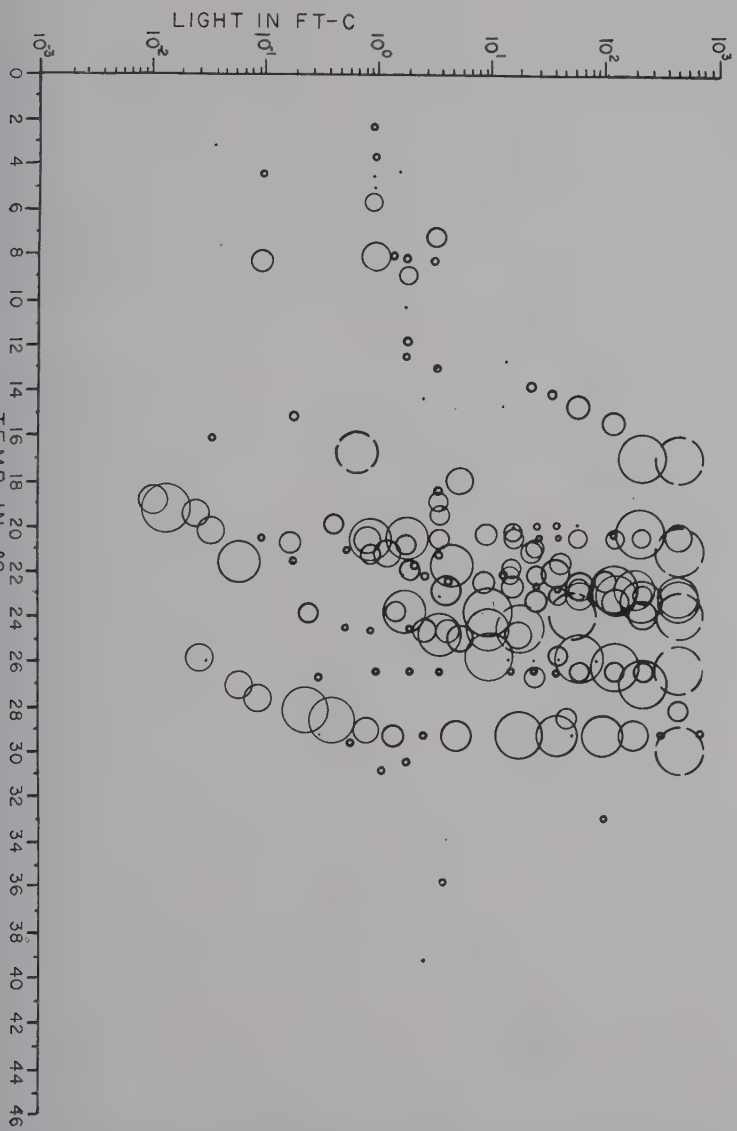

FIG. 3. Distribution of *Acartia tonsa* Dana, 1849 in the experimental apparatus. For explanation of the symbols used see Fig. 1.

Results

A total of 18 day tests were run. The distribution of each of the three copepod species used in the tests is shown graphically in Figures 1 through 3. The size of the circles used in the graphs indicate the per cent of the total count for the test run in each chamber. The broken circles indicate the terminal chambers with high concentrations. These would probably have been somewhat lower had additional chambers been present since some of the animals would probably have moved into them, thus decreasing the number in the chamber in question. The blank areas in the upper left and lower right corners of the figures indicate conditions which could not be reproduced in the experimental tank.

Acartia tonsa was the only form which occurred in sufficient numbers, throughout the year to permit its use in all the tests. Because of the inability to obtain one or both of the other species, *Calanopia americana, Paracalanus parvus*, for certain tests, the figures of the distribution of these two species are not as complete as that of *A. tonsa*.

We may consider the conditions covered by Figures 1 through 3 as falling into three temperature groups. The first is below 16°C, the second from 16 to 32°C, and the third is above this value.

In the medial temperature group, 16 to 32°C, large concentrations occurred from the highest illumination available, 500 foot-candles, to one of the lowest, 0.01 foot-candles. There was a slight tendency for the high concentrations to occur more frequently at higher illumination values.

In the temperature group below 16°C there was a marked exclusion of organisms from conditions of low illumination. Medium and large concentrations of organisms were associated with illumination values ranging from medium to the highest available under the experimental conditions. Above 32°C the reverse was true, the organisms being excluded from conditions of high illumination but present at medium illumination and occurring down to the lowest values available at that temperature range.

Discussion

Within the temperature range of 16 to 32°C there was a fairly general distribution of the experimental animals in relation to illumination. This temperature range most closely approximates that of the natural habitat throughout the year, 15.5 to 32°C (Chew, unpublished data).

This tolerance of a wide range in illumination is in agreement with the hypothesis that tolerance by an organism of any factor is greatest when the remaining factors have optimum values (Moore and Kitching, 1939).

Distribution in the first temperature range, below 16°C, appears to be modified by the adverse temperature conditions. The higher concentrations of the experimental animals are above 0.1 foot-candles of illumination. Since conditions of high illumination at low temperatures could not be provided experimentally, the distribution pattern of this area is unknown. It appears however, that low temperatures cause the forms to avoid conditions of lower illumination. Greater concentrations of the three species in the third temperature range, above 32°C, are absent from areas of high illumination, above 0.2 foot-candles. It thus appears that, at temperatures above the optimum range, the organisms tend to avoid conditions of high illumination.

It is thus shown that outside of the 16 to 32°C temperature range there is a correlation between the occurrence of copepod concentrations and illumination values. The sign of this correlation appears to depend on the temperature. Within the median temperature range there is little correlation of concentration with illumination. The dependance of response to one environmental factor on the status of a second is thus confirmed. There is some indication of a trend to concentration under conditions marked by an inverse relationship between illumination and temperature. Under abnormal natural conditions, such as the high temperatures found in some shallow water areas or the low temperatures which would be encountered if the forms were swept into deep water, this trend of movement would be in such a direction as to enable the forms to escape from the adverse conditions into those more suitable.

Summary

Previous field and experimental studies have shown that the vertical movement of zooplankton is controlled by illumination, temperature and pressure. The results of experimental work on the vertical distribution of inshore copepods in relation to existing conditions of light and temperature is given.

A description of the apparatus used in the experimental work is given with a discussion of the test procedure.

Experimental data indicated that within the temperature range similar to the annual range of the natural habitat there is a wide

distribution of the animals in relation to illumination values. Above and below this temperature range there is a modification of the response of the three species to illumination. The dependance of response to one environmental factor upon the status of a second is thus demonstrated. There is some indication of a trend from concentration under conditions marked by an inverse relationship between illumination and temperature.

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THE OCCURRENCE OF THE JELLYFISH *CHIROPSALMUS QUADRUMANUS* IN MATAGORDA BAY, TEXAS[1]

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ABSTRACT

Chiropsalmus quadrumanus L. Agassiz, a Scyphozoan of the order Cubomedusae not previously recorded in the Gulf of Mexico, is reported as occurring in great abundance in Matagorda Bay, Texas. The development of a large population coincided with drought conditions and high bay salinities along the Texas Gulf coast. When bay salinities dropped considerably in 1957 the jellyfish disappeared. The jellyfish were found to be living on or near the bottom at all times and preferred areas of soft mud. None were found in adjacent Gulf waters and adult forms in the bay showed no evidence of gonad development.

INTRODUCTION

In May 1955, in the course of a biological survey of Matagorda Bay on the central Texas coast, large numbers of the jellyfish *Chiropsalmus quadrumanus* L. Agassiz were encountered. During 1955 and 1956 they were found to be a major component of the invertebrate fauna of the embayment during summer and fall months. This species represented a painful nuisance, if not a real hazard, to bathers and fishermen in this area. The lesion produced by contact with the tentacles of the jellyfish was serious enough in some cases to require medical attention.

Recent faunal studies along the Texas coast by Gunter (1950), Reid (1955), and Parker (1955) have not reported *C. quadrumanus* in the Texas bays or in the adjacent Gulf waters. Hildebrand (1954) did not encounter this species during his studies of the fauna of the brown shrimp grounds off the Texas and Mexican coasts. Biologists of the Texas Game and Fish Commission Marine Laboratory staff have not reported this species during the course of their investigations. Two specimens now in the University of Texas Institute of Marine Science Museum were collected in Aransas Pass, Texas, on August 7, 1950, but other than this one instance there is no evidence of the occurrence of this jellyfish on the Texas coast.

DISTRIBUTION

Chiropsalmus quadrumanus is reported by Mayer (1910) as oc-

[1]Contribution No. 46 of the Texas Game and Fish Commission Marine Laboratory, Rockport, Texas.

curring from North Carolina to Brazil, and has been taken near Beaufort, N. C., by Mayer, and by Pearse, Humm and Wharton (1942).

Chiropsalmus is in the order Cubomedusae, which is stated by Mayer (1910) and by Hyman (1940) to contain some of the most noxious of the Scyphozoa. Fish and Cobb (1954) list *Chiropsalmus quadrigatus* Haeckel as the cause of some deaths in the south Pacific. Hedgpeth (1954) lists eleven species of Scyphozoa known to occur in the Gulf of Mexico. *Carybdea aurifera* Mayer, a rare species taken only at Tortugas, is the only representative of the Cubomedusae.

Mayer states that members of this order are inhabitants of warmer seas. While most have been taken in the open ocean, they are found swarming in harbors and other places near land. According to Fish and Cobb (*op. cit.*) medusae of this group congregate along the coasts for varying periods during the breeding season. Mayer also reports that when young they are bottom forms and when mature are found on the surface.

Distribution in Matagorda Bay

In Matagorda Bay *C. quadrumanus* was first taken in otter trawl samples in May 1955. At that time they had an average bell diameter of 18 millimeters. They were most abundant in August and September. By that time they had reached a maximum diameter of approximately 110 mm. The number decreased in October and by the middle of December none could be found. This cycle was repeated in 1956, the first being taken on May 17. The population declined in the fall and none were taken in trawl samples after late November. In 1957, however, only a few scattered specimens were taken in May and none were taken after the middle of July.

The jellyfish were most common in those parts of the bay where the bottom was soft mud and barren of attached vegetation. They were seldom taken on the grassy flats that are present along the north and west shores of the bay and along Matagorda Peninsula which separates the bay from the Gulf of Mexico. They were taken in the shallow bays as well as in areas where the water was 10 to 14 feet in depth. Few were found in the vicinity of Pass Cavallo, which connects the embayment with the Gulf of Mexico, and none were taken in the Gulf of Mexico adjacent to Pass Cavallo.

The jellyfish were found on or near the bottom and except in the fall were rarely seen washed up on the beaches with *Stomolophus*

meleagris Agassiz, *Aurelia aurita* Linnaeus and *Dactylometra quinquecirrha* Agassiz, the other Scyphozoans commonly inhabiting Texas bays. After a very low tide accompanying a "norther," *C. quadrumanus* was sometimes found stranded in the shallow waters in great numbers.

The jellyfish were rarely observed swimming near the surface but were taken in great numbers in the shrimp trawl. No attempt was made to count the numbers taken in trawl samples, but it appeared that during summer and fall months *C. quadrumanus* was about as abundant as *Stomolophus* and much more common than *Aurelia* and *Dactylometra*. Hedgpeth (1954) has commented on the great abundance of *Stomolophus* in Texas waters.

C. quadrumanus occurred in salinities ranging from 8 to 37 parts per thousand. Average bay salinities from January 1955 to January 1957 were approximately 30 ‰, and only in the small bays adjacent to streams did salinities fall below 20 ‰ for any length of time. The jellyfish were not common in those areas where salinities were below 20 ‰ and rarely were taken in areas where salinities were below 15 ‰. In the fall of 1956 many of the jellyfish in the shallow bays were killed and found floating on the surface following very heavy rains.

In 1957 the salinities in Matagorda Bay dropped considerably due to heavy rains throughout the state in the spring and early summer. Mean salinities and ranges in Matagorda Bay for April through August of 1956 and 1957 are given in Table 1. The means and ranges were taken from samples taken at ten stations in Matagorda Bay. A more detailed study of the hydrography of this area will appear elsewhere. During the same periods salinities in secondary bays such as Trespalacios Bay averaged 27 ‰ in 1956 and 10 ‰ in 1957. During June 1957 Trespalacios Bay was fresh or nearly so for most of the month.

TABLE 1

MEAN SALINITIES AND RANGES (IN PARTS PER THOUSAND) IN MATAGORDA BAY, TEXAS, 1956 AND 1957.

	1956		1957	
	Mean	Range	Mean	Range
April	27.6	26.8 - 28.6	24.9	16.0 - 30.5
May	26.5	24.7 - 27.5	19.1	11.2 - 25.0
June	28.3	26.8 - 30.0	12.2	4.0 - 15.8
July	30.6	28.6 - 32.0	14.7	11.1 - 19.1
August	33.6	32.9 - 34.5	20.4	16.0 - 28.0

In May 1957 only a few scattered specimens were taken and these were confined to the deeper parts of the bay where the water is 10 to 14 feet in depth. Scattered specimens were found in June and in early July. The last specimen was taken on July 18, 1957. At no time were they found in the shallow water or near shore where they had been abundant in the two previous summers.

Discussion

Little is known about the life history of *C. quadrumanus*. Scyphozoan medusae were not recognized in plankton samples and the smallest medusae taken were found in shallow water some distance from the inlet. It is possible that reproductive stages occurred in the bay although none of the specimens examined appeared to have developing or mature gonads. The smallest medusae taken in trawl samples had an average bell diameter of 18 mm. They were well developed except for the pedalia, which varied in the young specimens from four to eight branches, and the subumbrellar sacs, which were very small in the young specimens.

The stomachs in all specimens examined appeared empty except for small particles which could not be identified. The Cubomedusae have been reported to subsist mostly on fish (Hyman, 1940), but in this case it appears that the jellyfish were feeding on small bottom forms or on detritus.

Local shrimp fishermen estimate that the jellyfish have been present in Matagorda Bay for at least five or six years. Specimens were taken at Aransas Pass in 1950, and it seems probable that this species has been present in other Texas bays in the past and failed to become established. J. W. Hedgpeth has suggested (personal communication) that it is possible that there are always a few strays of widely distributed species such as this, and it is only on rare occasions that conditions are just right for them to develop a large population.

The recent drought, extending from 1948 to 1956, increased bay salinities along the central Texas coast. The changes in the invertebrate fauna, apparently resulting from these changes in salinity, have been discussed by Parker (1955). *C. quadrumanus* is considered an oceanic form and, as previously indicated, cannot tolerate low salinities for any length of time. The waters of Matagorda Bay during the drought period approached the salinity of the Gulf. In addition the bay has a soft mud bottom and there is little tidal action. These conditions allowed for the development of a large population which

disappeared when salinities in the bay returned to a more normal level in 1957.

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STUDIES ON THE PULMONATE GASTROPOD *SIPHONARIA PECTINATA* (LINNAEUS) FROM THE SOUTHEAST COAST OF FLORIDA[1]

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Abstract

Studies and observations on the pulmonate gastropod *Siphonaria pectinata* (Linnaeus) from the southeast coast of Florida are given. The feeding, habitat, spawning, larval development, environmental and geographical variation, geographical distribution and growth of the species are discussed. The veliger, egg masses and newly settled young are illustrated.

Introduction

Two species of *Siphonaria, S. pectinata* (Linnaeus) and *S. alternata* (Say), are found along the Florida coast. *S. pectinata* is the common species on the east coast from Fernandina south to the upper Florida Keys. In the lower keys, *S. alternata* is the common limpet.

Hubendick (1946) in his large systematic work on the Patelliformia considers the form of *S. pectinata* (=*S. naufragum* Stearns 1872, =*S. lineolata* Orbigny 1842) from Florida and the West Indies to be a variant and suggests that it be named *S. p.* forma *lineolata* Orbigny. He has discussed the phylogeny of the species in his earlier major work on the siphonariids (1945). Kohler (1898) carried out the pioneer anatomical investigations on *S. pectinata* in his overall study of the anatomy of the genus *Siphonaria*. Dieuzeide (1935) studied *S. algesirae* (Quoy and Gaimard) (=*S. pectinata)* on the Algerian coast. His work dealt mainly with the anatomy, histology and embryology of the animal. In the present work, the author has turned her attention to the biology of *S. pectinata* as it lives in nature in hopes of more nearly completing our knowledge of this species.

Populations at eight localities along the coast of southeast Florida were included in this study. The areas extended from Blowing Rocks (Jupiter) southward to Key Largo (Fig. 1).

This work was initiated under the guidance of Hilary B. Moore of The Marine Laboratory, University of Miami, and to him the author wishes to extend her thanks. She is also grateful to her husband, Gilbert L. Voss, for his suggestions and supporting interest. The author also wishes to extend her thanks to the various students at The Marine

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Laboratory who have collected specimens for her on their field trips.

Habitats and Feeding

S. pectinata lives in the intertidal zone attached to a hard substratum which in the localities studied varied from rugged limestone cliffs at Blowing Rocks, a granite block breakwater at Boca Raton, limestone rocks at Ragged Key IV and Key Largo to cement sea walls at Bear Cut, Coconut Grove and Soldier Key. Scattered specimens were also occasionally found living on wood pilings and mangrove roots but none were found on metal surfaces though such were available intertidally at several places visited. *S. pectinata* was also found living almost permanently submerged on isolated rocks well below low water at Bear Cut and Coconut Grove. Baker (1891) reported *S. lineolata* Orbigny (=*S. pectinata)* off Vera Cruz, Mexico, living on coral in 10-20 feet of water.

S. pectinata lives in greatest concentration on surface covered only by a film of microscopic algae. In many areas, individuals live in close association with macroscopic algal mats. At Bear Cut, part of the population was found living in cleared areas within mats of *Bostrychia tenella,* a mosslike alga common intertidally in this region. At Boca Raton and Coconut Grove, *Siphonaria* was found living in cleared patches within mats of *Ulva lactuca* and *Enteromorpha flexuosa.* All the *Siphonaria* found living (their shell scars indicated that they were "home") in these mats of algae, occurred singly, in pairs or in small groups.

In every case, so far observed, there was an increased average and maximum size of *S. pectinata* where mats of *Ulva* and *Enteromorpha* were present. *Siphonaria* in association with *Bostrychia,* however, showed no tendency toward increased size. In south Florida, large mats of *Ulva* and *Enteromorpha* are associated with areas of pollution or otherwise enriched waters. In such places, the microscopic algal film on the rocks would be expected to be richer and heavier affording a greatly increased food supply. Since only a minority within a population live in close association with the algal mats, it suggests that the heavier film of microscopic algae, rather than the macroscopic algae, accounts principally for the increased size of the animals. Fischer-Piette (1948) similarly reported an increased growth rate for *Patella vulgata* near sewer outfalls where the organic content of the water was higher than normal.

Stomach analysis of *S. pectinata* showed the presence of the larger algae, diatoms and microscopic algae.

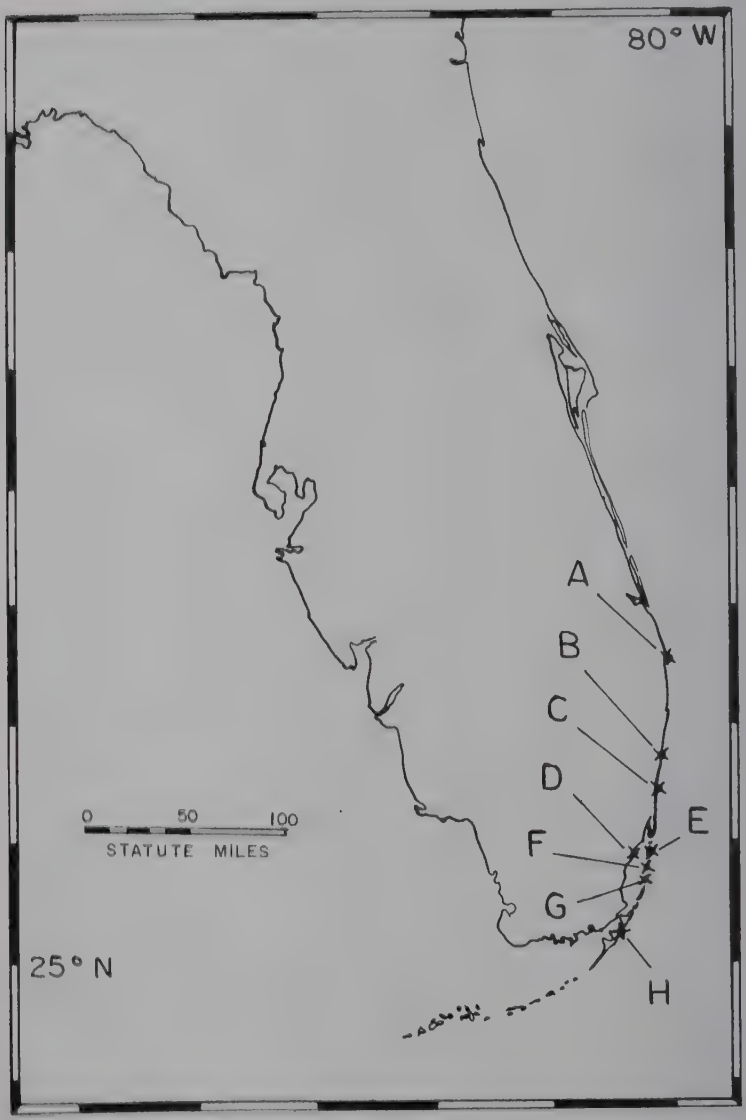

FIGURE 1. The eight localities along the southeast coast of the Florida peninsula and the Florida Keys which were included in this study. A.—Blowing Rocks (Jupiter); B.—Boca Raton; C.—Ft. Lauderdale; D.—Coconut Grove, Miami; E.—Bear Cut, Biscayne Key, Miami; F.—Soldier Key; G.—Ragged Key IV; H.—Key Largo.

Zonation

S. pectinata typically inhabits the "balanoid zone" but often extends some distance below and, depending on the exposure, some distance above it. Populations of the species tend to concentrate around midtide (MT), tapering gradually downward to mean low water (MLW) and rather sharply upward to the upper limit of the splash zone (USZL). This typical distribution may be distorted by heavy wave action or by the crowding of other organisms.

Figure 2 diagramatically presents this latter effect. Here the zonation of *S. pectinata* on the sea wall at Coconut Grove is shown with those of the other chief space-competitors, the barnacles *Tetraclita squamosa, Balanus amphitrite* and *Chthamalus* spp. The kites are not drawn to the scale of numbers per area because it is not necessary for

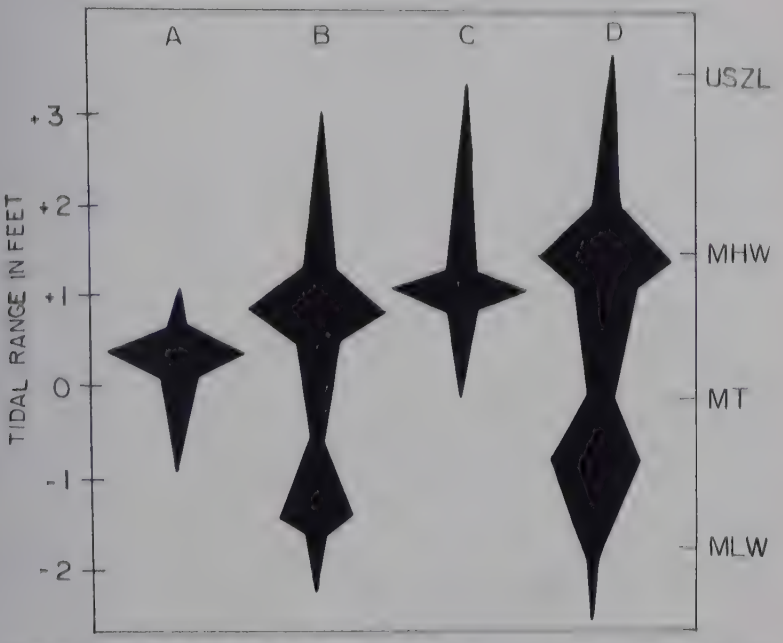

Figure 2. Distortion of the intertidal distribution of *Siphonaria pectinata* (Linnaeus) by the crowding of other organisms on the Coconut Grove seawall, Miami, Florida. A. *Tetraclita squamosa;* B. *Balanus amphitrite;* C. *Chthamalus* spp.; D.—*Siphonaria pectinata.*

the purpose of showing the distortion. The tidal range, which is normal for this area, is about 2.5 feet, shown exaggerated here by about one-third because of the 45° angle of the sea wall. The splash zone extends about 2 feet above mean high water (MHW). *Tetraclita* is concentrated in a narrow zone just above MT and thins out rapidly above and below it. The concentration of *Balanus* is midway between MT and MHW, and again to a lesser extent just above MLW. *Chthamalus* spp. is concentrated slightly higher than the upper belt of *Balanus* and is scattered slightly higher in the splash zone than *Balanus*. *S. pectinata* inhabits the widest range, extending from about 1 foot below MLW to about 6 inches above the upper limit of the splash zone. The population is found to be concentrated in two areas, one at MHW above the *Chthamalus* belt and the other midway between MT and MLW above the lower belt of *Balanus*.

On the cliffs at Blowing Rocks (Jupiter), the *Siphonaria* did not extend down to MLW because of a sandy beach strip and few were found at the base of the cliffs MT, probably because of the abrasive action of the sand. As the author abruptly discovered, the surf at this station was quite heavy and extended the splash zone about 5 feet above MHW. The *Siphonaria* ranged to the upper limit of the splash zone and concentrated around MHW.

On the sea wall at Bear Cut, the wave action was slight. The *Siphonaria* were concentrated around MT; they extended down to just below MLW and scattered to just above MHW.

Spawning and Larval Development

S. pectinata on the southeast coast of Florida spawns during the winter months. At Bear Cut, over a period of 3 years observation, much spawn was found from December through February. Egg ribbons were numerous on the Coconut Grove seawall when visited in March, 1952. At Boca Raton, there was much spawn in February, 1951 and, in March of the following year, scattered ribbons were observed as well as many new young of 2-5 mm. The *Siphonaria* at Blowing Rocks were observed with spawn in February, 1951 and February, 1952. Morrison (1958) reported *S. pectinata* to spawn in an aquarium shortly after collecting them from Miami Beach in November, 1955.

The author has observed *S. pectinata* at numerous other localities along the southeast Florida coast for the past 7 years and has never found spawn except during these cooler months of December to March. During this period, the mean coastal surface water temperatures range

from about 70° to 74°F in contrast to 75.8° to 86.1°F for the rest of the year (Miami Beach Tide Station data).

On the Algerian coast, Dieuzeide (op. cit.) reported that *S. algesirae (=S. pectinata)* spawned during nearly all of the year but that during the summer months of July, August and September, the spawn was scarce. During these three months the sea surface temperature averages between 72.5° to 75°+F, while that for the remainder of the year averages between 57.5° to 70°F (U. S. Hydrographic Office, 1944).

The spawn of *S. pectinata* consists of small oval ribbons about 3-4 cm long, 3 mm wide and 2 mm high (Fig. 3a). The egg ribbons were found from just below MLW to MT. They were entangled one over the other or found singly in the shape of a semi-circle. When in this latter form, the ribbon sometimes partly encircles a limpet at its home scar

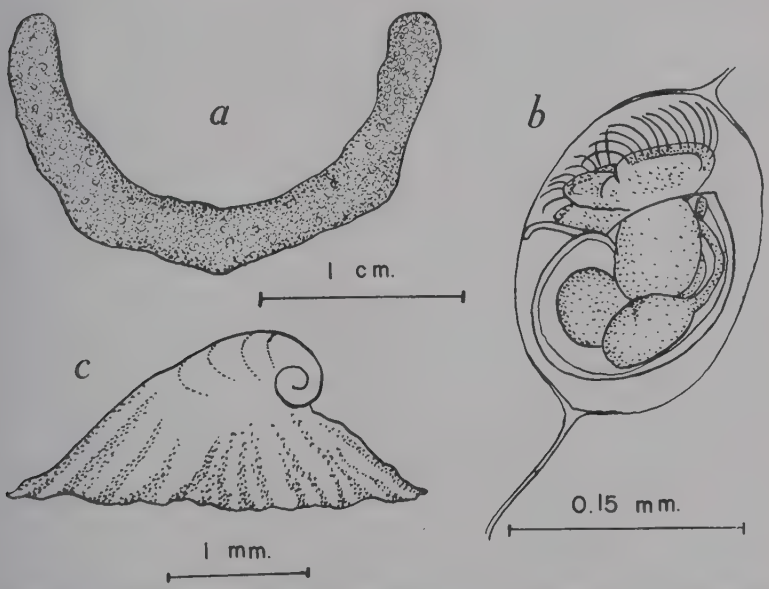

FIGURE 3. *Siphonaria pectinata* (Linnaeus). A.—Egg mass; B.—Egg capsule containing the veliger immediately before hatching; C.—Juvenile shell showing nuclear whorls.

but usually the individual spawns away from "home." The color of the egg ribbon varies from yellow-green to light yellow. The consistency of the mass correlates with the color; the yellow-green masses are com-

pact and firm, the light yellow masses are soft and flabby. Examination showed that the lighter the color of the mass, the more developed were the embryos contained in it. The ribbon is filled with numerous egg-shaped capsules irregularly spaced in a jelly-like matrix, the whole being enclosed by a toughened wall. The egg capsule is about 0.15 mm wide and 0.19 mm long. It is formed of two membranes, the outer one appearing to be continuous with a fine thread that connects with another capsule, thus uniting them into strands.

Spawn collected in the field was easily hatched in the laboratory by keeping it wet with fresh sea water. Immediately before hatching, the veliger shell measures approximately 0.15 mm wide and 0.14 mm high (Fig. 3b). It is yellowish-brown and slightly twisted. The veliger has a well developed velum with long cilia and a well developed foot and operculum. Dieuzeide (op. cit.), who had specimens spawn in aquaria, reported that the veliger larva is fully formed in about 20 days from egg laying. On the southeast Florida coast where the climate is warmer, development probably requires a shorter period of time.

When ready to hatch, the veligers began to rotate by vigorously beating their cilia. They broke open their capsules and forced their way through the matrix and the surrounding wall. Upon hatching, they usually sought the bottom of the container. The stimulation of one veliger rotating or of mechanical probing of the surface of the mass started all of the veligers in the area to rotate, resulting in whole sections breaking free at a time. A sudden wetting of the ribbon, whose surface had previously been dry, would also initiate hatching. This is probably the natural stimulant for those egg ribbons laid above LW level. None of the veligers would settle even though rocks and other rough surfaced objects were introduced into the bowls. Under laboratory conditions, the veligers lived for 2 to 4 days. It is possible that *S. pectinata* larvae exhibit a gregariousness similar to that observed with the pelagic larvae of several other marine animals, principally the barnacles (Knight-Jones, 1953 and others). If rocks with already established *Siphonaria* were presented, the veligers might be attracted to settle. The average size of the ribbons, egg capsules and hatching veligers from southeast Florida is larger than that reported by Dieuzeide from the Algerian coast.

The author examined many young from the different stations. Nuclear whorls were clearly visible on most of the juveniles studied up to 4 mm shell length (Fig. 3c) and occasionally on 5 and 6 mm specimens. The brownish hyalin nucleus is sinestrally whorled for the

first one and a half turns after which it widens to acquire the patelliform shape of the adult shell.

Environmental and Geographical Variation

Hubendick (1946) considers *S. pectinata* from Florida and the West Indies to be a variant which should be named *S. p.* forma *lineolata* Orbigny. The deviation is in color pattern. His description follows: "On the outer side it has forking, brown, somewhat irregular lines, separated by distinct interspaces. On the interior, but only peripherally, there are dark radial lines, tapering inwards to a central point. Centrally the color is usually a yellowish white." As he further states: "there are transitional forms connecting the variant to the main group of the species."

In the specimens examined from southeast Florida, the author found the interior color pattern to be the most variable character. In several cases it varied greatly even within a single population. This was most markedly seen at Soldier Key where the specimens could be grouped into a series from a form with relatively few dark radial lines with wide white interspaces to a form with so many dark radial lines as to give the interior a dark brown appearance except for the extreme center. The central color varied from white to yellowish-brown. At other localities, the interior color pattern was quite constant within a single population. For instance, in Blowing Rocks' specimens the dark radials were moderate in number with clear white interspaces.

At all localities visited during this study, the HW specimens were all found to be taller than the lower level ones with the exception of an occasional stray. Cook (1911) reported this same finding with *S. algesirae* (=*S. pectinata)* from the Mediterranean. He, like Russell (1909) working with the limpet *Patella vulgata,* correlated this variation with the degree of exposure to wave action, the more flattened shell being an advantage to the animal at the lower levels by offering less resistance to the impact of the waves. This explanation would necessitate separate breeding populations to explain the regular existence of the two forms in a single area. Orton (1933), on the other hand, correlated the length of time of exposure to the air to shell growth and suggested that a high tide individual, being more exposed to desiccation, tended to contract down on the rock and in this position the new shell formed would be taller and thicker than that of a lower tide individual which, being wet most of the time, lived with a more expanded mantle. This explanation was confirmed experimentally by Moore

(1934). A similar variation between high and low water specimens occurs with the limpets of the genus *Acmaea* (Test, 1945).

At Boca Raton, 50 MHW specimens and 50 MLW specimens were collected and the height and length measured. The H/L ratio of the MHW specimens was 46.7 ± 3.35. That of the MLW specimens was 35.1 ± 3.34, a difference of about 25 per cent. Cross sections were made of the same shells and though the MHW specimens were slightly thicker than the MLW ones, the difference was not nearly as marked as that described by Moore *(op. cit.)* in *P. vulgata*.

At most of the localities visited, an occasional specimen exhibited "ledging" on its shell. This apparently resulted from the individual moving its "home" from one tidal level to another and acquiring the accompanying different type of shell growth. Moore *(op. cit.)* found this situation in *P. vulgata* when he moved tall high water individuals to permanent submergence in a pond.

Crowding by barnacles and surface irregularities of the substratum often affects the outline shape of the shell. Specimens, particularly at Boca Raton, were found with shell margins irregularly indented to fit into a particular space between barnacles or in a crevice in the rock.

Hubendick (1946) reported another type of variation in *S. pectinata* attributed to environment. He described a specimen taken at the mouth of the Gambia River in Africa whose shell was very thin with the apex prolonged and recurved, the outer surface being marked by thin concentric ridges. The only explanation for this variation was its proximity to fresh water from the river. Test *(op. cit.)* found that reduced salinity resulted in a thinner shell than normal in the limpet *Acmaea fenestrata*.

Working with West African material, Hubendick (1950) suggested the possibility of geographical variation occurring in *S. pectinata*. The best measureable genetic character which appeared to vary from one population to another was the number of radii in the exterior shell sculpture and pattern. The radii count of a single quadrant (frontal left quadrant) was used. This count was divided by the shell length to eliminate any effect of size. The present author made similar radii analyses on about 50 specimens each from Jupiter, Boca Raton, Bear Cut and Soldier Key. The results accompanied by standard deviations are given in Table 1. The number of radii in a population in southeast Florida appears to be slightly more variable than that in an African population as given by Hubendick, but it still shows a definite variation between populations which may be attributed to geographical isolation.

TABLE 1

THE MEANS OF THE *Exterior Shell Radii Count (Frontal Left Quadrant)/Shell Length* AND THEIR STANDARD DEVIATIONS OF ABOUT 50 SPECIMENS FROM EACH OF FOUR POPULATIONS OF *Siphonaria pectinata* (LINNAEUS) FROM SOUTHEAST FLORIDA SHOWING POSSIBLE GEOGRAPHICAL VARIATION.

Locality	*Radii Index*
Jupiter	1.55 ± 0.24
Boca Raton	1.06 ± 0.11
Bear Cut	1.64 ± 0.22
Soldier Key	1.28 ± 0.16

GEOGRAPHICAL DISTRIBUTION

The geographical distribution as shown on the map in Figure 4 was compiled chiefly from Hubendick (1946) with local data added from Baker (1891), Johnson (1934), Whitten (1950) and Stephenson (1950). In the Mediterranean, *S. pectinata* occurs along the African coast and the coast of Spain; in the Eastern Atlantic from Portugal to the Cameroons with a break at the Gulf of Guinea; the Azores; the Cape Verde Islands; and in the Western Atlantic from Fernandina, Florida, to the Texas-Mexican border; off Vera Cruz, Mexico; Cuba; St. Thomas; Guadeloupe and Trinidad. The Riksmuseum, Stockholm, has examples from Valparaiso, Chile. *S. lineolata* Sowerby which Hubendick *(op. cit.)* gives as questionable in his synonomy of *S. pectinata* is reported on the Pacific Coast from Central America and from Guayaquil, Ecuador, to Chile.

Hubendick (1945) suggests as a possible explanation for the distribution of the siphonariids that they originated in the Tethys Sea of the Miocene period. If so, the above distribution of *S. pectinata* could be explained.

Hutchins (1947) has outlined general patterns of correlation between zonal distribution boundaries of marine organisms and winter or summer extremes of temperature. The northern limit of *S. pectinata* in the Atlantic appears to be explainable by such seasonal extremes of water surface temperatures (Fig. 4). The northern boundary in Florida and in Portugal in the Atlantic and in Spain in the Mediterranean is well delimited where the 55°F isocryme (Hutchins and Scharff, 1947) approaches the coasts. Above this line the winter minimum appears to be too cold for the species. Since *S. pectinata* prefers the colder temperatures for spawning (it spawns nearly year around on the Algerian

FIGURE 4. Geographical distribution of *Siphonaria pectinata* (Linnaeus) and the poleward limits described by the 55°F isocryme.

coast), the northern limitation must be based on survival rather than breeding.

On the other hand, the southward distribution appears to be affected by whether the winter minimum is cool enough for spawning (breeding limitation). (On the southeast Florida coast spawning takes place, as stated earlier, only in the winter months when the surface temperatures drop to the year's low of about 74° to 70°F.) No one isocryme describes the southern limit on both sides of the Atlantic. This is explainable if a certain degree of maintenance of a low temperature is essential for spawning rather than the temperature alone.

The 55°F isocryme describes the southward boundary of *S. lineolata* (?=*S. pectinata)* in Chile. The northern boundary in Central America is uncertain.

With regards to local distribution on the Florida Keys, the Stephensons (1950) found only *S. pectinata* on the northern keys (they reported on Soldier, Elliot and Plantation Keys) and only *S. alternata* on the most southern keys (West Summerland, Key West). The author has not had the opportunity to collect along the lower keys but has from several of the upper keys (Soldier, Ragged IV, Largo), where specimens of *S. alternata* were found scattered among the more numerous *S. pectinata.* Hubendick (1946) gives the distribution of *S. alternata* as extending up the east coast of Florida. Since *S. pectinata* is found as far south as Trinidad, there is every reason to believe that it is found scattered among the more numerous *S. alternata* in the southernmost keys. *S. alternata* can probably tolerate a higher minimum temperature in its life-cycle and therefore might be expected to be the more common of the two species in their mutual range on southward of the Florida Keys.

The Stephensons *(op. cit.)* also noted that all of the *Siphonaria* were found on the oceanic side of the keys, none being found on the Florida Bay side. Florida Bay is an extensive body of shallow water and, because of this, the temperature of the surface water is above average for the area and, during the winter dry season, the salinity of the Bay rises sharply. Both of these abnormal conditions would be unfavorable for the animals.

Growth

Growth studies were made on *S. pectinata* both by marking specimens and by monthly measurings of the same population. The work was done with the Bear Cut population. The monthly measurements were made on an isolated group of about 500 specimens from July,

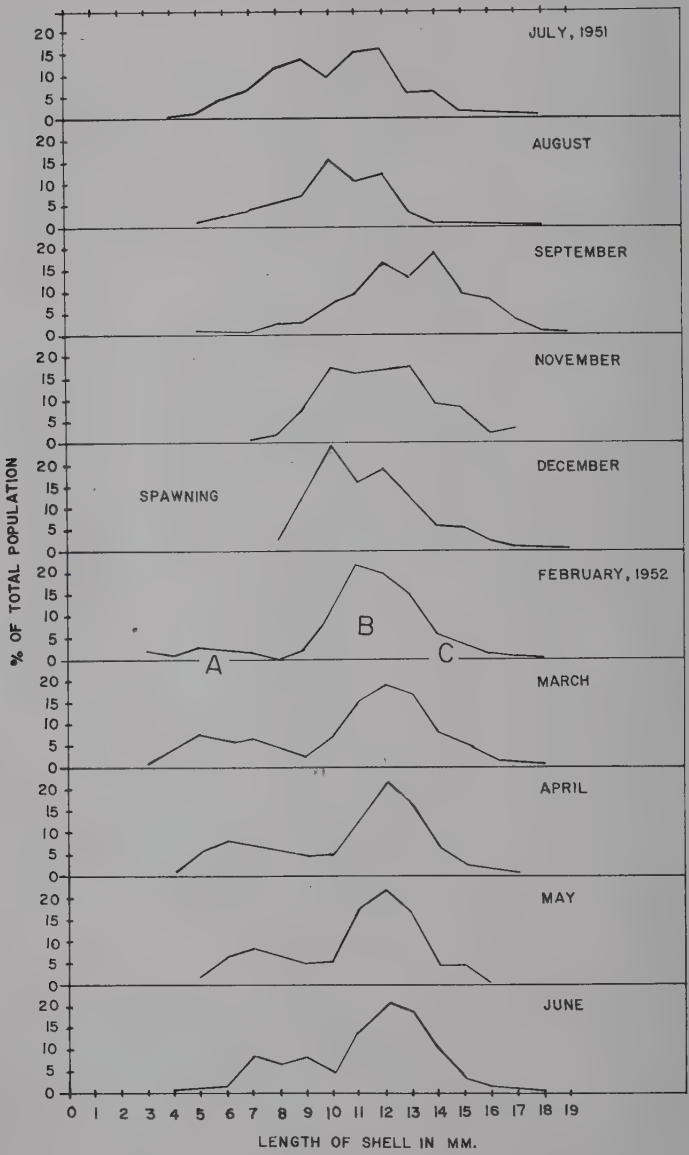

FIGURE 5. The monthly measurements of a population of about 500 specimens of *Siphonaria pectinata* (Linnaeus) from Bear Cut, Biscayne Key, Miami, Florida, from July, 1951 to June, 1952.

1951 to June, 1952. The individuals were measured to the nearest millimeter. The results are graphed in Figure 5.

In February, 1952 the author selected three different size stages in the population which appeared to exhibit different rates of growth, i.e., 6 mm, 11 mm, 14 mm. As many of each group as could be found were marked with different colored nail polish. Each month after measuring, the polish marking was renewed. At the end of the first month there was a 96 per cent recovery, at the end of the second month 58 per cent, and at the end of the third month 26 per cent recovery. Because the recovery was so unsatisfactory the marking was discontinued. From the measurements of the marked specimens it was calculated that the 6 mm individuals grew an average of 1.2 mm per month, the 11 mm individuals an average of 0.6 mm per month and the 14 mm specimens an average of 0.4 mm per month.

From the monthly measurement graph (Fig. 5), it is difficult to separate the definite age groups except for the newly spawned of the year (group "A"). These hatched in December and January grew an average of about 2-2.5 mm per month until they attained about 6 mm shell length.

These growth rates, of course, could not be applied on a year around basis since growth in invertebrates is so dependent on temperature, food availability and breeding periods. If the population breakdown in Figure 5 is at all close to being true, then the "B" group in February, 1952 would be composed mostly of one and two year olds and the "C" group of three and possibly some four year olds.

Summary

1. *Siphonaria pectinata* populations from eight localities along the coast of southeast Florida were studied.

2. *S. pectinata* lives in greatest concentration on intertidal hard substratum covered only by a film of microscopic algae. The species showed an increase in average and maximum size in areas where mats of *Ulva* and *Enteromorpha* were found. Large mats of these algae are associated in this region with areas of enriched waters. It is believed that the resultant increased food supply in the form of a heavier film of microscopic algae rather than the macroscopic algae accounts for the increased animal size.

3. The spawning of *S. pectinata* on the southeast coast of Florida is confined to the winter months of about December through March.

4. The interior color pattern of the shell varied greatly even within a single population. The number of radii in the exterior shell sculpture

appears to show a variation between populations which may be attributed to geographical isolation as suggested by Hubendick (1950).

5. The northern and southern limits of the worldwide distribution of *S. pectinata* appear to be explainable by seasonal temperature extremes. In the Atlantic the winter minimum may limit the survival of the species to the north and may affect the spawning to the south. On the Pacific coast the conditions are in reverse.

6. Growth studies were done both by marking specimens and by monthly measurements of a population. In the population studied, the newly hatched grew about 2.2.5 mm per month for the first 2–3 months and then dropped to a rate of about 1–2 mm per month. Individuals of about 11 mm grew about 0.6 mm per month. Individuals of about 14 mm grew about 0.4 mm per month.

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YOUNG SCOMBROID FISHES FROM THE GULF OF MEXICO

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ABSTRACT

Examination of some fish collections, made in the Gulf of Mexico from June, 1954 to August, 1956 by personnel of the United States Fish and Wildlife Service, have resulted in the separation and identification of young forms of several tuna and tuna-like species. These include the yellowfin tuna *(Thunnus argentivittatus)*, blackfin tuna *(Thunnus atlanticus)*, oceanic skipjack *(Katsuwonus pelamis)*, little tunny *(Euthynnus alletteratus)*, frigate mackerel *(Auxis thazard)*, and bonito *(Sarda sarda)*, as well as a few small specimens of *Thunnus* of indeterminate species. The methods of diagnosis employed are discussed, and some species are described and illustrated.

The capture of these young fishes indicates that several scombroid species spawn in the Gulf of Mexico at various times of the year.

INTRODUCTION

The United States Fish and Wildlife Service has been engaged fo several years in an intensive survey of the fishery resources of th Gulf of Mexico and adjacent waters (Galtsoff, 1954). Numerou collections of fishes of the Gulf region have resulted from explora tory fishing and gear development work, conducted mainly from th Service research vessel M/V OREGON. Recently, we have had th opportunity to examine some of these collections from which we hav been able to separate and identify young forms of several scombroi species. The present paper summarizes our methods and results.

We wish to thank Edgar L. Arnold, Jr., Harvey R. Bullis, Jr George A. Rounsefell, and their associates in the Bureau of Com mercial Fisheries, U. S. Fish and Wildlife Service, for the loan o the OREGON fish collections and the Director, Bureau of Commercia Fisheries, U. S. Fish and Wildlife Service, for permission to publis our findings. James E. Böhlke of the Academy of Natural Science of Philadelphia kindly permitted us to examine specimens from thei accessions. We are also indebted to Mary Jane Fitzenkotter an Barbara M. Klawe, both of Mercy Hospital, San Diego, for prepar ations of microscopic sections, and to Ann Schleif and Robert L Wisner of the Ocean Beach Medical Group and University of Cali fornia Scripps Institution of Oceanography, respectively, for assist ance in obtaining x-rays.

Methods and Materials

The material upon which our studies are based represents only a part of the collections of young tuna and tuna-like fishes made in the Gulf of Mexico by Service personnel between June, 1954 and August, 1956. We have not yet been able to examine other specimens known to have been taken on cruises of the OREGON during this same period, as well as those collections made prior to June, 1954 and subsequent to August, 1956. Detailed data for the stations listed in the sections on material examined are given by Springer and Bullis (1956) and supplementary sheets.

All specimens, which were preserved in formalin, were examined under a binocular microscope and were dissected, stained, sectioned, or x-rayed as necessary for identification. Gill-raker counts were made in each case from the first arch of the right side. Our measurements of total length represent the direct distance from the tip of the snout to the tip of the shortest median ray in the caudal fin.

We have followed, for convenience, the taxonomic nomenclature of Rivas (1951). However, it may be noted that Rivas (1954), following Ginsburg (1953), recognizes *Thunnus albacares* rather than *T. argentivittatus* as the correct name for the Atlantic yellowfin tuna. Also Rivas has placed the various tunas in the expanded family Scombridae.

Results

Identification and description of young scombroids. There are present in all of the collections available to us a total of 1,256 young scombroid specimens among which we have tentatively identified the following genera and species: *Thunnus argentivittatus* (Cuvier), *T. atlanticus* (Lesson), *Katsuwonus pelamis* (Linnaeus), *Euthynnus alletteratus* (Rafinesque), *Auxis thazard* (Lacepede), and *Sarda sarda* (Bloch). In addition, a number of larval and juvenile forms were recognized as *Thunnus*, but could not be assigned to species, as will be discussed later.

Yellowfin Tuna, *Thunnus argentivittatus;* Blackfin Tuna, *T. atlanticus;* and *Thunnus sp. indet.*

Material examined. Thunnus argentivittatus: OREGON sta. 1088 (3,26-31 mm). *Thunnus atlanticus* OREGON st. 1088 (1,26), 1121 (4,28-34), 1134, (1,29), 1142 (1,25), 1178 (1,36), 1399 (1,26), Aug. 1956, 28°50′N, 87°50′W (4,25-37). *T. argentivittatus* or *T. atlanticus*: 1088 (1,19), 1121 (2,27-39), 1171 (1,19), 1360 (2,

5.5-8), 1367 (1, 23), 1399 (2, 15), Aug. 1956, 28°50′N, 87°50′W (11, 21-22).

We have 36 young tunas (*Thunnus*) ranging in total length from 5.5 to 39 mm. All were dipnetted under a night-light except two, the smaller individuals in the series, which were found in plankton net collections.

The two planktonic specimens which measure 5.5 and 8 mm, respectively, are difficult to identify because of their small size and early stage of development. However, the large size of the head relative to the rest of the body, the sharply pointed snout with well-developed teeth on the jaws, and the prominent pre-opercular spines indicate that these are indeed larval scombroids. The darkly pigmented first dorsal fins suggest that these fish are either *Thunnus* or *Euthynnus,* but the absence of chromatophores on the symphysis of the pectoral girdle and rami of the lower jaws establish their identity as young *Thunnus.* We are unable at this time to refer these very small specimens to species.

The remaining larger individuals were first examined externally for identifying features. One of the smaller juveniles (27 mm) was subsequently sectioned serially, and a larger individual (34 mm) was also dissected, to study the relative position of the internal organs which, for some species of tunas, is diagnostic. In addition, five specimens of various sizes were stained for bone study with alizarin red, using the techniques of Clothier (1950).

Our results indicate that all of these juveniles are young thunnids. Not only does their general appearance coincide with published descriptions and illustrations of young tunas but the vertebral formula for each individual is 18 (precaudal) + 21 (caudal) for a total of 39 vertebrae which is definitive of fishes of the family Thunnidae (Kishinouye, 1923; Godsil and Byers, 1944). Moreover, on our stained specimens, the anterior part of the lateral line is visible and its curvature in each case corresponds to that attributed to Thunnidae by Kishinouye (1923).

Specific identification of the larger juveniles was also attempted, but the difficulties attendant to this work were compounded by the knowledge that as many as five species of *Thunnus* may inhabit the Gulf of Mexico. They are the yellowfin tuna (*T. argentivittatus*), bluefin (*T. thynnus*), blackfin tuna (*T. atlanticus*), albacore (*T. alalunga*), and bigeye tuna (*T. obesus*). Of these, the albacore has

been caught only off Jamaica and Hispanola in the western Atlantic Ocean (Bullis and Mather, 1956), while the bigeye tuna reaches the Atlantic coast of the United States (Mather and Gibbs, 1958). We have presumed that these two species are rare and most likely absent from the Gulf region. Certain anatomical features also exclude the possibility that our juvenile specimens are young albacore, provided the same arrangement obtains for Atlantic tunas as found by Godsil and Byers (1944) for Pacific species. Our microscopic sections show that the spleen is located on the right side of the body, in ventral view, whereas in albacore this organ is usually on the left side. The intestine also runs posteriorly on the right side of the abdominal cavity instead of along the left side as is characteristic of albacore.

A third alternative, *T. thynnus,* was eliminated because the first closed haemal arch of all of our specimens appears at the eleventh vertebra instead of at the tenth, which is reported to be typical of bluefin tuna (DeSylva, 1955).

The remaining two species are the yellowfin tuna (*T. argentivittatus*) and the blackfin tuna (*T. atlanticus*), both of which are common in the Gulf of Mexico (Bullis, 1955). While adult yellowfin tuna may be distinguished from adult blackfin tuna by such superficial characters as coloration, the best means of separation is the use of gill raker counts. DeSylva (1955) gives a gill raker range of 4-6+ 15-19, total 19-24, for *T. atlanticus* and 7-10 + 19-22, total 26-32, for *T. albacares* (=*T. argentivittatus*).

Rivas (1951, p. 222) has stated, "The young of *T. argentivittatus* and *T. atlanticus* are distinguishable with certainty only by gill raker count." The problem of identifying our small specimens, however, is not as simple or as definitive as Rivas has implied because we do not know for each of these species the size at which the full complement of gill rakers is attained nor the variation in number of gill rakers among individuals of the same size.

In order to examine these matters, we counted the gill rakers of 26 of our 34 young thunnids, ranging in size from 15 to 37 mm, for which gill rakers are observable. Complete counts for each specimen are given in Table 1. Also, in Figure 1, we have plotted the total numbers of gill rakers of each fish against its total length. The number of gill rakers increases steadily with size up to about 25 mm. Thereafter, the pattern is rather confused and we can discern two

groups: individuals with gill raker counts from 19 to 22 and, at similar sizes, those possessing from 27 to 31 counts, with one individual having an intermediate count of 25. If we assume, as seems reasonable from a consideration of the counts from adult yellowfin and blackfin tuna previously given, that the range of variation between individuals of the same size and species is not likely to be as great as that exhibited by our specimens at sizes 26, 31, and 36 mm, we may conclude that we have representatives of not one but two species. Accordingly, we have provisionally identified as yellowfin tuna (*T. argentivittatus*) specimens no. 14, 22, and 25 of Table 1, all of which have the higher gill-raker counts and which, interestingly enough, were taken at the same station. The gill-raker counts of the remaining individuals of 25 mm length and larger, with one exception, fall within the range accorded blackfin tuna (*T. atlanticus*). The single

TABLE 1
GILL-RAKER COUNTS OF YOUNG TUNAS, *Thunnus*, FROM THE GULF OF MEXICO.

Specimen no.	*Total length (mm)*	*Gill-raker Counts*				*Station no.*
		Upper arch	*Middle*	*Lower arch*	*Total*	
1	15	0	1	8	9	1399
2	19	1	1	12	14	1171
3	19	1	1	11	13	1088
4	21	3	1	10	14	*
5	21	3	1	11	15	*
6	21	1	1	12	14	1294
7	22	3	1	11	15	*
8	22	3	1	14	18	*
9	23	3	1	15	19	1367
10	23	4	1	14	19	1399
11	25	5	1	15	21	1142
12	25	4	1	15	20	*
13	26	5	1	16	22	1399
14	26	5	1	21	27	1088
15	26	4	1	16	21	1088
16	28	4	1	14	19	1121
17	29	4	1	16	21	1121
18	29	4	1	15	20	1134
19	30	4	1	15	20	*
20	30	4	1	15	20	*
21	31	4	1	15	20	1121
22	31	6	1	21	28	1088
23	34	4	1	14	19	1121
24	36	5	1	16	22	1178
25	36	7	1	23	31	1088
26	37	4	1	20	25	*

*Station occupied during July, 1956 at 28°20′N., 87°50′W.

37 mm specimen with a gill-raker count of 25 is also tentatively diagnosed as a blackfin juvenile because of the upper arch count of four as compared to a count of seven for the 36 mm yellowfin tuna. Those individuals whose gill-raker counts could not be determined and those smaller than 25 mm may belong to either of these species. Further study of our material and the examination of additional specimens may help to resolve this problem of species identification, and we do not discount the remote possibility that species other than *T. atlanticus* and *T. argentivittatus* may be included among our very small specimens.

Figure 2 illustrates a 28 mm juvenile presumed to be a young blackfin tuna. We have found that pigmentation patterns are often quite useful in identifying small scombrids and have, therefore, outlined our observations for this particular specimen.

The first dorsal fin is heavily pigmented, but is not entirely black. A few faint chromatophores are visible at the anterior basal portion of the second dorsal fin, which is otherwise colorless. A darkly pig-

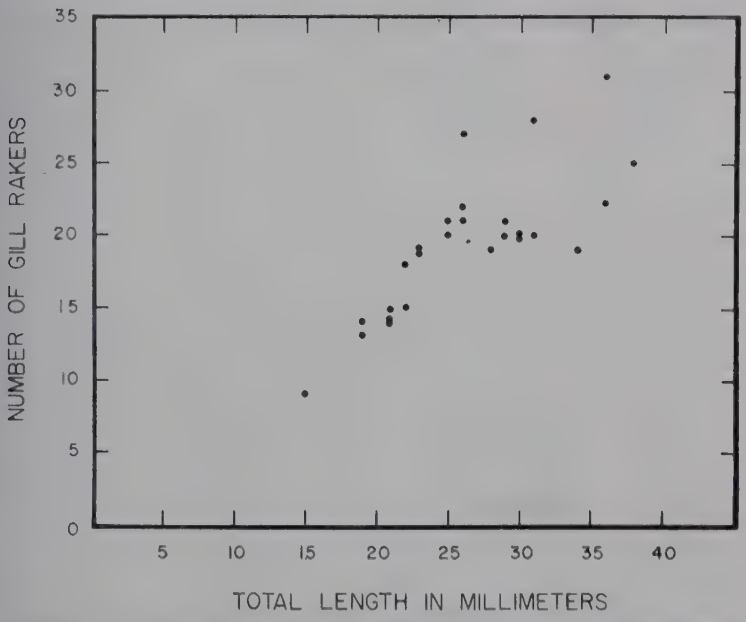

FIGURE 1. Gill-raker counts of young *Thunnus* plotted against total length.

mented area colors the top of the head and extends forward to the brain region. The dorsal portion of the body is heavily pigmented, but coloration does not extend caudally beyond the fifth dorsal finlet. A concentration of pigment is present along the lateral line and in some areas along the dorsal and lateral regions, resulting in a faint pattern of six vertical bars not unlike "parr" marks of young salmonids. Scattered chromatophores in the peritoneum are visible through the body wall, particularly in the abdominal region. The first ray of the pectoral fin is slightly pigmented and several large chromatophores are present on the operculum. The posterior margin of the orbit is pigmented and the tips of the lower jaw and snout are also colored. The portion of the snout between the two anterior nares is marked by scattered chromatophores. Some chromatophores appear at the base of the caudal fin, but are more concentrated in the upper half.

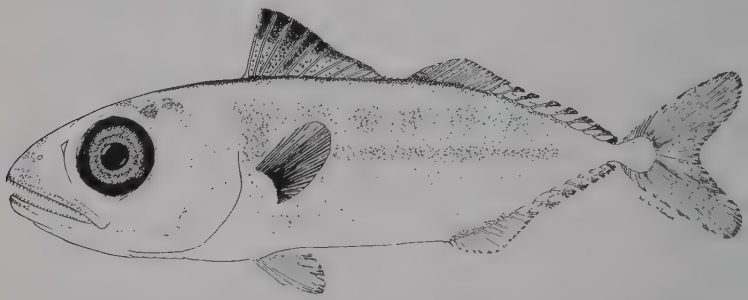

FIGURE 2. A 28 mm juvenile provisionally identified as a young blackfin tuna, *Thunnus atlanticus,* from OREGON station no. 1121, July 17, 1954.

As far as we have been able to determine, the coloration and general appearance of this juvenile is identical to that of specimens referred by us to yellowfin tuna. However, a slightly pigmented area is present on the inner surface of the operculum of all of our yellowfin specimens which is absent from those identified as blackfin tuna. This character may or may not be important.

Oceanic Skipjack, *Katsuwonus pelamis*

Material examined. OREGON sta. 1362 (1, 56), 1367 (2, 47-50), 1370(2, 29-45), 1378 (1,49).

This species is represented by six small specimens of total length 29 to 56 mm, which were collected by dipnet during 1955. All of

these agree in description with that given by Schaefer and Marr (1948a) for juvenile *K. pelamis* collected by them in the Pacific Ocean, off Central America. Examination of a stained and cleared 45 mm individual and x-rays of three specimens, 49 to 56 mm in length, revealed the presence of a "trellis" formed by the fusion of the inferior foramen of the vertebrae and the haemal arches. This skeletal development is diagnostic of the family Katsuwonidae (Kishinouye, 1923; Godsil and Byers, 1944). The vertebral number of 41 (20 + 21), including the urostyle, further establishes the identity of our specimens as *Katsuwonus pelamis*. The genus *Euthynnus*, which also belongs to Katsuwonidae, is separable from *Katsuwonus* by its typically lower vertebral count of 39 or fewer (Kishinouye, 1923; Godsil, 1954).

Little Tunny, *Euthynnus alletteratus*

Material examined. OREGON sta. 1110 (4, 27-41), 1124 (4, 28-33), 1127 (86, 21-44; for details of capture see Bullis, 1955a), 1134 (3, 26-38), 1138 (2, 76-80), 1171 (38, 11-47), 1174 (4, 56-108), 1183 (5, 24-36), 1185 (29, 22-174), 1318 (10, 21-31), 1360 (4,3.5-5.3), 1362 (88, 30-53), 1367 (16, 31-55), 1368 (4, 6.2-8), 1370 (90, 29-65), 1372 (116, 4-80), 1374, (60, 17-68). 1378 (11, 49-86), 1380 (12, 32-94), 1399 (52, 24-49), 1477 (8, 19-29), Aug. 1956, 28°50′N, 87°50′W (33, 21-82).

The little tunny, *E. alletteratus*, is the best represented of all scombroid species in the OREGON material. There are on hand 679 individuals of sizes between 4 mm and 174 mm. This fairly good array of specimens greatly facilitated their indentification as *Euthynnus*. The following characters in particular were noted for the larger juveniles: (1) the presence of a skeletal "trellis" similar to *Katsuwonus* but within 39 vertebrae instead of 41 as in the latter, and (2) very long right lobe of the liver (Godsil, 1954). Larval forms were diagnosed from pigmentation (Matsumoto, 1958).

Euthynnus consists of three species, *E. alletteratus*, the little tunny of the Atlantic coast, *E. lineatus*, the black skipjack of the Pacific west coast, and *E. yaito*, the Hawaiian or Japanese black skipjack. Godsil (1954) has given a complete account of the characters which may be used to distinguish among these three species. Therefore, it may suffice to state that our specimens were assigned to *alletteratus* because of the presence of 39 vertebrae and the absence of vomerine teeth. Also, *alletteratus* is the only species known to occur in regions adjacent to the Gulf of Mexico.

Gill rakers are considered a useful criterion for separating *alletteratus* from *yaito*, which is similar in appearance and structure. *E. alletteratus* has 37-40 gill rakers while *yaito* has a range of 29-33 (Godsil, 1954). However, as shown in Figure 3, where we have plotted the total gill-raker counts of each of three specimens, where available, selected at random for each size larger than 20 mm, this character appears to be valid for *E. alletteratus* only at sizes of about 60 mm or larger. At smaller sizes, other features need to be considered for the identification of *alletteratus* and their separation from related species.

As a point of interest, we note that Ehrenbaum (1924) in his early work described and figured what he thought might be the young forms of *E. alletteratus* but which, at the same time, he conjectured might well be those of the frigate mackerel *Auxis*. Our specimens at similar sizes do not correspond in shape or in pigmentation to those of Ehrenbaum and we are inclined to accept the identity of his specimens as *Auxis*.

Figure 4 (a, b, c) illustrates, respectively, a 4 mm, 6.5 mm, and 58 mm *E. alletteratus* from the Gulf of Mexico. The presence of a chromatophore in the region of the symphysis of the pectoral girdle,

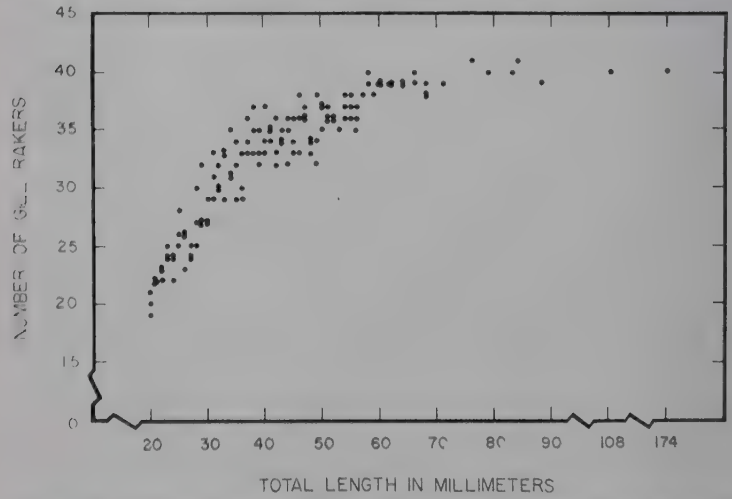

FIGURE 3. Gill-raker counts of young *Euthynnus alletteratus* plotted against total length.

as known by our two small specimens, is characteristic of *Euthynnus* at these sizes. Chromatophores are usually found also along the mid-ventral line in the posterior region of the body and along the rami of the lower jaw. In the larger juveniles, vertical bars appear faintly along the dorsal region and number from six to nine in our specimens. This pattern does not appear to be confined to *alletteratus* but is exhibited by *E. yaito* and *E. lineatus* as well, judging from the descriptions and illustrations of Kishinouye (1923), Schaefer and Marr (1942), Wade (1950), and Clemens (1956).

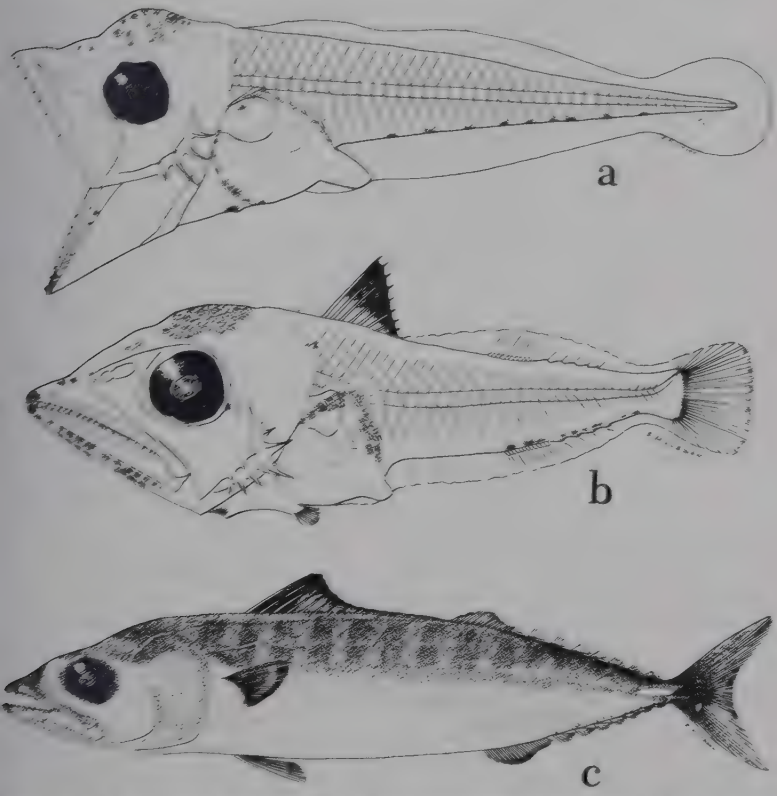

FIGURE 4. *Euthynnus alletteratus*. a. 4 mm specimen. OREGON sta. 1372, August 21, 1955. b. 6.5 mm specimen. OREGON sta. 1372, August 21, 1955. c. 58 mm specimen. OREGON sta. 1372, August 21, 1955.

Frigate Mackerel, *Auxis thazard*

Material examined. OREGON sta. 1088 (2,17-34), 1110 (34, 26-39), 1113 (8, 23-62), 1119 (2, 23-25), 1124 (1,30), 1127 (9, 22-27), 1134 (2, 45-49), 1139 (1, 46), 1171 (2, 14-25), 1174 (2, 65-110), 1183 (7, 21-33), 1185 (15, 21-145), 1318 (3, 20-25), 1360 (1, 5.5), 1362 (2, 38), 1370 (178, 26-56), 1372 (1, 40), 1374 (13, 28-40), 1378 (1, 97), 1380 (3,31-65), 1399 (99, 15-77), 1470(2, 65-74), 1477 (136, 15-52), 1492(7, 70-87), 1585 (1, 88), 1593 (1, 69).

We have among our collections 533 young frigate mackerel ranging in length from 5.5 to 145 mm. This cosmopolitan species is easily recognized by its body shape and by the separation between dorsal fins (Godsil, 1954). For larval forms, where the fins are not yet fully developed, pigmentation is an excellent diagnostic character as has been shown by Matsumoto (1958).

Godsil (1954), referring to the data of Fitch, has given the gill-raker formula of Pacific frigate mackerel as 9-12 + 1 + 30-36 for a total of 40-49. Postel (1956) found a range of 40-45 for five Mediterranean specimens. Our counts for Gulf of Mexico *Auxis* fall within the ranges given by these investigators, but we did not encounter any specimens approaching the upper limits of gill-raker numbers observed in Pacific frigate mackerel. Furthermore, as may be seen from Figure 5, where we have plotted the total gill-raker

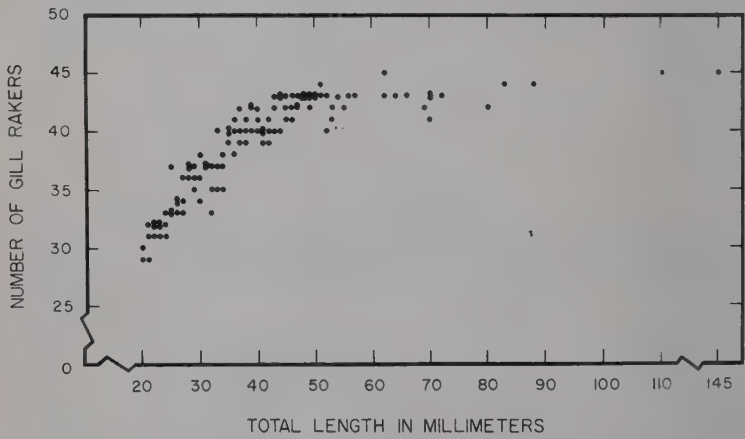

FIGURE 5. Gill-raker counts of young *Auxis thazard* plotted against total length.

counts of some of our specimens against corresponding total lengths in the same manner as previously for *Euthynnus,* the full complement of gill-rakers is not attained at sizes less than about 40 mm. Counts from adults, therefore, are not applicable to the identification of small specimens.

Bonito, *Sarda sarda*

Material examined. OREGON sta. 1470 (2, 64-67).

Two specimens of bonito are present in our collections from the Gulf. These measure 64 and 67 mm in total length; the latter appears in Figure 6. The presence of 20 spines in the first dorsal fin and a gill-raker count of 7 + 11 serve to identify these fish as young *S. sarda* (Rivas, 1951).

The bonito is common along the Atlantic coast of the United States and only recently has been found to occur in the Gulf of Mexico. Springer and Bullis (1956) report the capture of adults in the area of Arcas Bay (20°12′N, 91°59′W) in the southwestern Gulf region.

Spawning habits of scombroid fishes in the Gulf of Mexico. The collection and identification of larval and juvenile fishes not only provide useful taxonomic information but contribute importantly to the delineation of areas and seasons of spawning. In the latter application, the assumption is made that the presence of very young fish is indicative of recent spawning in an area at or near the time of capture. Such an inference may not be reasonable for those kinds of fishes for which the time of hatching of the egg is long, and the rate of growth of the young is slow, particularly in areas where the passive displacement of eggs and larvae by ocean currents may be fairly extensive. These factors, however, do not appear to constitute serious sources of error in the interpretation of our data because (1) the time of incubation of tuna eggs is thought to be short, about two days at most for some species (Schaefer, 1956), (2) young tropical tunas grow very rapidly (Clemens, 1956), and (3) velocities of surface currents in the Gulf of Mexico do not appear to be very great (Leipper, 1954). Nevertheless, we should note that our samples are not complete in time or space and that our deductions with respect to the spawning habits of the tuna and tuna-like fishes of the Gulf are, therefore, limited.

We have plotted in Figure 7 the localities of capture of the several species represented in our material for the purpose of indicating those areas within the Gulf of Mexico where spawning most likely occurs. Most of our specimens are from stations within a fairly well circum-

FIGURE 6. A 67 mm *Sarda sarda* specimen from OREGON station no. 1470. March 25, 1956.

scribed area southeast of the Mississippi River delta. This concentration relative to other areas may reflect sampling intensity rather than the distribution of young forms, but apparently the northcentral Gulf region is definitely a spawning locality for all of the species identified by us with the exception of the yellowfin tuna (*Thunnus argentivittatus)* and the bonito *(Sarda sarda)* which may also reproduce in this particular area. Specimens of the latter two species were taken only at single stations, in the northwestern Gulf and the central Gulf, respectively. However, while previous information on the spawning behavior of the bonito in the Gulf region is lacking, some data are available for yellowfin tuna. Bullis (1955b) reports the capture of sexually mature yellowfin tuna in the Gulf of Campeche and in the northern Gulf and the collections of young fish at widely scattered stations during the summer and early fall months. Therefore, this commercially important species probably spawns throughout the Gulf region.

FIGURE 7. Localities of capture of young scombroid specimens identified from some OREGON collections in the Gulf of Mexico from June, 1954 to August, 1956.

The widespread distribution of young frigate mackerel *(Auxis)* as shown in Figure 7 is not surprising in view of observations made in the Pacific (unpublished data) which show the species to be ubiquitous in its spawning.

The dates of capture (obtainable from Springer and Bullis, 1956) provide a basis for inferences as to the time of spawning of the several tunas and related species in the Gulf of Mexico. The months in which young forms were collected in some or all years represented in the OREGON collections are: *Thunnus argentivittatus*: June; *T. atlanticus*: June, August, September; *T. argentivittatus* or *atlanticus*: April, June, July, August; *Katsuwonus pelamis*: August; *Euthynnus alletteratus*: March, April, June, July, August; *Auxis thazard:* March, April, June, July, August; *Sarda sarda:* March. It appears from these data that from March through September, at some time or another, several tunas and their near relatives engage in reproductive activity. However, information presently available does not preclude the occurrence of spawning at other times of the year.

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